AD-A066 361 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 8/3
NEWBURYPORT HARBOR, MASSACHUSETTS; REPORT 1. DESIGN FOR WAVE PR--ETC(U)
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TECHNICAL REPORT HL-79-1

NEWBURYPORT HARBOR, MASSACHUSETTS

Report 1

DESIGN FOR WAVE PROTECTION AND EROSION CONTROL

by

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February 1979

Report 1 of a Series

Approved For Public Release; Distribution Unlimited

Prepared for U. S. Army Engineer Division, New England
Waltham, Massachusetts 02154

(14) WES-TR-HL-79-1

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report HL-79-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) NEWBURYPORT HARBOR, MASSACHUSETTS; Report 1, DESIGN FOR WAVE PROTECTION AND EROSION CONTROL; Hydraulic Model Investigation		5. TYPE OF REPORT & PERIOD COVERED Report 1 of a series 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Charles R. Curren Claude E. Chatham, Jr		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Hydraulics Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Engineer Division, New England 424 Trapelo Road Waltham, Mass. 02154		12. REPORT DATE (11) February 1979 13. NUMBER OF PAGES 119 (12) 134p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (9) Technical rept. Dec 76 - Sep 77		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Bank erosion
Bank protection
Erosion control
Hydraulic models
Newburyport Harbor, Mass.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A 1:75-scale (undistorted) hydraulic model of Newburyport Harbor, Massachusetts, which included the lower 5,700 ft of the Merrimack River, approximately 2,300 ft of the Atlantic coastline on each side of the harbor entrance, and sufficient offshore area to permit generation of the required test waves, was used to investigate the arrangement and design of proposed improvements with respect to riverbank erosion control, wave protection, and CONT

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20. ABSTRACT (Continued)

river flow conditions. The proposed improvements consisted of (a) changes in the length of the north jetty, (b) changes in the crown elevation of the north jetty, and (c) addition of groins at two locations. An 80-ft-long wave generator, a water circulating system, crushed coal tracer material, and an automated data acquisition and control system (ADACS) were used during model operation.

It was concluded from model test results that:

a. For moderate to large incident waves, existing conditions are characterized by turbulent wave conditions in the entrance channel and strong longshore currents in the area between the south jetty and Plum Island Point, resulting in continued northeasterly movement of tracer material along the eroding portion of Plum Island.

b. Of the improvement plans tested involving raising the north jetty crown elevation (plans 1-1B), plan 1 (crown elevation +11.0 ft) was selected as the optimum with respect to wave protection and construction costs.

c. Of the improvement plans tested involving the north jetty extension (plans 2-2E), plan 2B (900-ft extension) was selected as the optimum with respect to wave protection, prevention of erosion on Plum Island, and construction costs.

d. Of the south groin plans tested, plan 3A (north jetty crown elevation +11.0 ft) provided better wave protection than plan 3 (north jetty crown elevation +8.3 ft).

e. The plans tested involving both north and south groins (plans 4 and 4A) resulted in extremely large current velocities in the entrance channel, and might cause erosion of Plum Island and navigation problems.

f. Of the plans tested, plans 2B, 3, and 3A all provided adequate erosion protection for the northern end of Plum Island. Plan 3 requires the least volume of rock but does not improve entrance wave conditions. Plan 2B provides the optimum entrance wave conditions but requires the greatest volume of rock. Plan 3A offers adequate erosion protection while improving entrance wave conditions and appears to be the optimum plan with regard to protection provided and cost.

PREFACE

A request for a wave-action model investigation of the entrance to Newburyport Harbor, Massachusetts, was initiated by the Division Engineer, U. S. Army Engineer Division, New England (NED), and authorization for the U. S. Army Engineer Waterways Experiment Station (WES) to perform the study was granted by the Office, Chief of Engineers, U. S. Army. Funds were authorized by NED on 24 June and 14 October 1976.

The model study was conducted at WES during the period December 1976 through September 1977 in the Wave Dynamics Division (WDD) of the Hydraulics Laboratory under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Dr. R. W. Whalin, Chief of the Wave Dynamics Division. The tests were conducted by Messrs. C. R. Curren, Project Engineer, with the assistance of R. E. Ankeny, electronics technician; K. A. Turner, computer specialist; and J. P. Ruark and P. M. Krasnoff, engineering student trainees, under the supervision of Mr. C. E. Chatham, Chief of the Wave Processes Branch, WDD. This report was prepared by Messrs. Curren and Chatham and is Report 1 of a series.

During the course of the investigation, liaison was maintained between NED and WES by means of conferences, telephone communications, and monthly progress reports.

Messrs. Carl Hard and Frank Notardonato, NED, visited WES to observe model operations and participate in conferences during the course of the study.

In addition to the wave-action model study reported herein, a distorted-scale (1:100 vertical, 1:300 horizontal) model of Newburyport Harbor, the Merrimack River to the head of tidal influence, and a portion of the Atlantic Ocean adjacent to the harbor entrance was used to study the effects of proposed improvement plans on hydraulic, salinity, flushing, and entrance shoaling and scour conditions. The study was conducted during the period from August 1973 to September 1977. Results of the study will be published separately as Report 2.

COL John L. Cannon, CE, was Commander and Director of WES during

the conduct of this investigation and the preparation and publication of this report. Mr. Fred R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
miles per hour (U. S. statute)	1.609344	kilometres per hour
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589988	square kilometres

NEWBURYPORT HARBOR, MASSACHUSETTS

DESIGN FOR WAVE PROTECTION AND EROSION CONTROL

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. Newburyport Harbor is located on the northern coast of Massachusetts, about 54 miles* by water north of Boston and 20 miles southwest of Portsmouth, New Hampshire (Figure 1). Newburyport Harbor was constructed during the period July 1881-October 1914. The city of Newburyport is the principal business center for several nearby towns and the summer resorts of Plum Island and Salisbury Beach, which are situated on the south and north sides, respectively, of the entrance to Newburyport Harbor.

The Problem

2. Between 19 and 27 February 1969, three large storms entered the Merrimack Embayment and caused irreparable damage to the riverbank inside the south jetty. Waves overtopping the north jetty eroded approximately 260 ft of sand from the front of the U. S. Coast Guard Station located there; the resulting loss of sand totaled about 1,080,000 cu yd. In an attempt to halt the erosion process, a revetment was installed in front of the Coast Guard Station. The effect of this revetment was a transfer of the problem upriver.[1]

Purposes of the Model Study

3. The purposes of the model study were to:

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* A table of factors for converting U. S. customary units of measurement to metric (SI) is presented on page 4. All dimensions used in this report are given in prototype units unless otherwise noted.

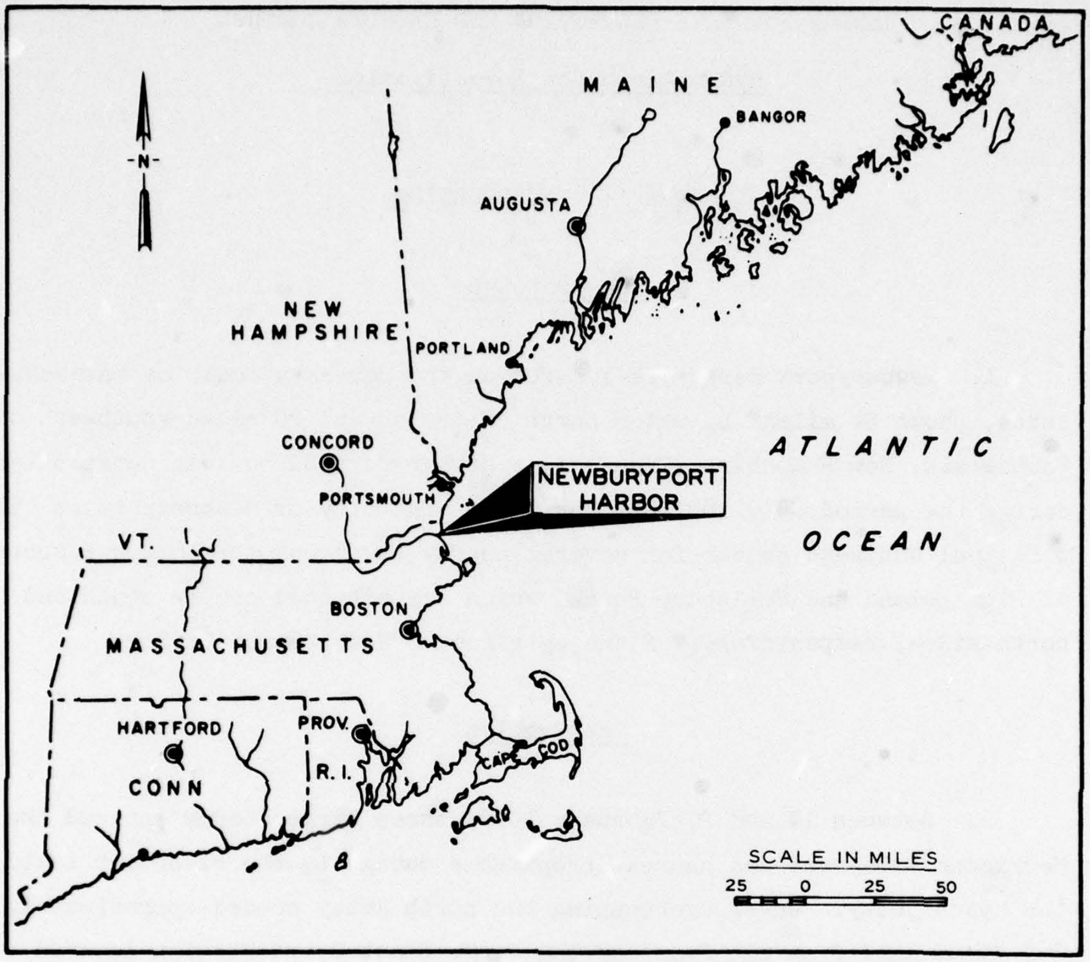

Figure 1. Project location

a. Determine the mechanism by which sand is being lost from the riverbank inside the south jetty.

b. Study shoaling and wave conditions with the proposed improvement plans installed in the model.

c. Develop alternative remedial plans for the alleviation of undesirable conditions as found necessary.

d. Determine whether suitable design modifications of the proposed plans could be made that would reduce construction costs significantly and still provide adequate protection.

PART II: THE MODEL

Design of the Model

4. The Newburyport Harbor model (Figure 2) was constructed to a linear scale of 1:75, model to prototype. Scale selection was based on such factors as:

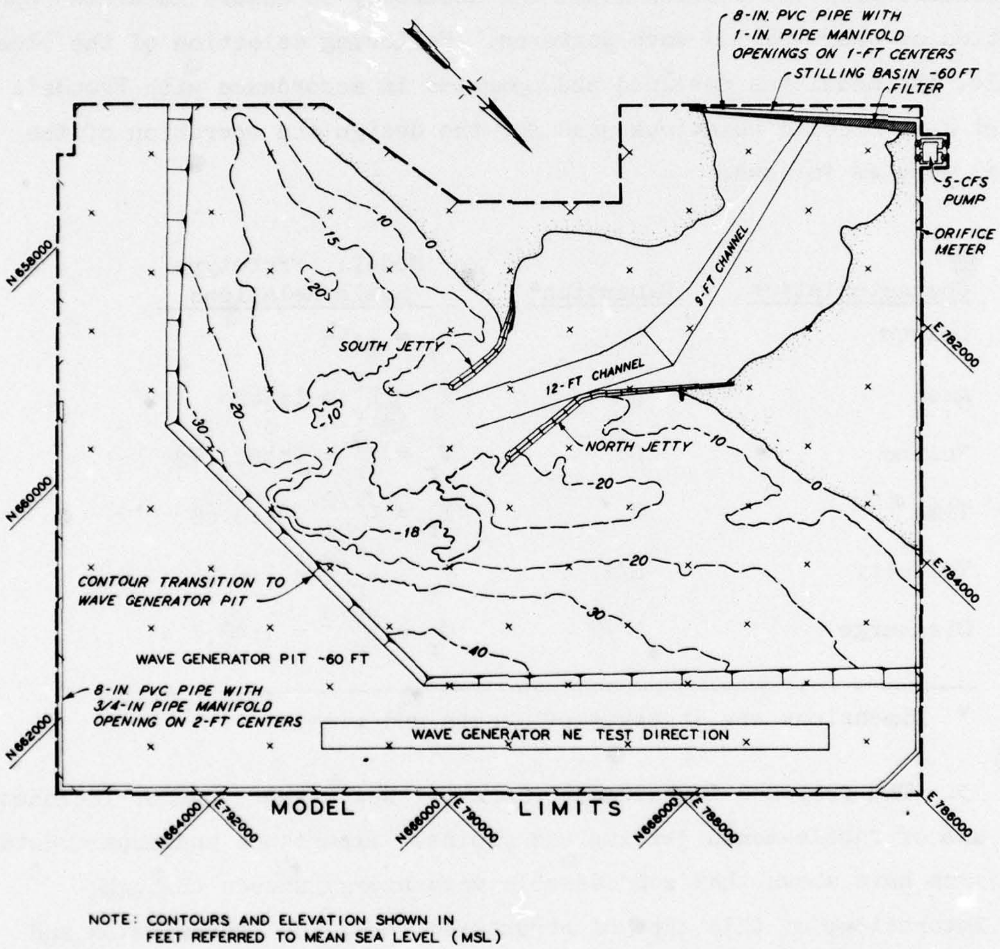

Figure 2. Model layout

a. Depth of water required in the model to prevent excessive bottom friction effects.

b. Absolute size of model waves.

c. Available shelter dimensions and area required for model construction.

d. Efficiency of model operation.

e. Capabilities of available wave-generating and wave-measuring equipment.

f. Model construction cost.

A geometrically undistorted model was necessary to ensure accurate reproduction of short-period wave patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law.[2] Scale relations used for the design and operation of the model were as follows:

Characteristics	Dimension*	Model: Prototype Scale Relations
Length	L	$L_r = 1:75$
Area	L^2	$A_r = L_r^2 = 1:5625$
Volume	L^3	$V_r = L_r^3 = 1:421{,}875$
Time	T	$T_r = L_r^{1/2} = 1:8.66$
Velocity	L/T	$V_r = L_r^{1/2} = 1:8.66$
Discharge	L^3/T	$Q_r = L_r^{5/2} = 1:48{,}714$

* Dimensions are in terms of length and time.

5. The proposed improvement plans for Newburyport Harbor included the use of rubble-mound jetties and groins. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type of structure; thus, the transmission and absorption of wave energy became a matter of concern in the design of the 1:75-scale model. In small-scale harbor models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than do geometrically similar prototype structures.[3] Also,

transmission of wave energy through the structure is relatively less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations[4,5] at the U. S. Army Engineer Waterways Experiment Station (WES), this adjustment was made by determining the wave energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A section was then developed for the small-scale three-dimensional model that would provide essentially the same relative transmission of wave energy. Therefore, based on previous findings for structures and wave conditions similar to those at Newburyport Harbor, it was determined that a close approximation of the correct wave energy transmission characteristics could be obtained by increasing the size of the rock used in the 1:75-scale model to approximately 1.5 times that required for geometric similarity. Accordingly, in constructing the jetty and groin structures in the Newburyport Harbor model, rock sizes were computed linearly by scale and then multiplied by 1.5 to determine the actual sizes to be used in the model.

6. Ideally, a quantitative, three-dimensional, movable-bed model investigation would best determine the effectiveness of various project plans for the alleviation of riverbank erosion due to wave action in Newburyport Harbor. However, this type of model investigation is difficult and expensive to conduct, and each area in which such an investigation is contemplated must be carefully analyzed. The following computations and prototype data are considered essential for such investigations[6]:

- a. A computation of the littoral transport, based on the best available wave statistics.
- b. An analysis of the sand-size distribution over the entire project area (offshore to a point well beyond the breaker zone).
- c. Simultaneous measurements of the following items over a period of erosion and accretion of the shoreline (this measurement period should be judiciously chosen to obtain the maximum probability of both erosion and accretion during as short a time span as possible):

(1) Continuous measurements of the incident wave characteristics. Such measurements would mean placing enough redundant sensors to accurately estimate the directional spectrum over the entire project area, and in addition would mean conducting a rather sophisticated analysis of all these data.

(2) Bottom profiling over the entire project area using the shortest time intervals possible.

(3) Nearly continuous measurements of both littoral and onshore-offshore transport of sand. These measurements would be especially important over the erosion-accretion period. A wave forecast service would be essential to this effort to prepare for full operation during the erosion period.

7. In view of the complexities involved in conducting movable-bed model studies and due to limited funds and time for the Newburyport Harbor project, the model was molded in cement mortar (fixed-bed) at an undistorted scale of 1:75 and a tracer material was used to determine qualitatively the degree of sediment movement for various plans.

The Model and Appurtenances

8. The model reproduced the existing Newburyport Harbor entrance, approximately 2,300 ft of the Atlantic coastline on either side of the harbor entrance, and underwater contours to an offshore depth of 40 ft with a sloping transition to the wave generator pit elevation* of -60 ft. The total area reproduced in the model was approximately 9,500 sq ft, representing about 1.9 square miles in the prototype. Vertical control for model construction was based on mean sea level (msl). Horizontal control was referenced to a local prototype grid system. Figure 3 is a general view of the model.

9. Model waves were generated by an 80-ft-long wave generator with a trapezoidal-shaped vertical-motion plunger. The vertical motion of the plunger caused a periodic displacement of water incident to this

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* All elevations (el) cited herein are in feet referred to mean sea level (msl).

Figure 3. General view of model

motion. The length of the stroke and the period of vertical motion were variable over the range necessary to generate waves with the required characteristics. In addition, the wave generator was mounted on retractable casters, which enabled it to be positioned to generate waves from the required test directions.

10. A water circulating system (Figure 2) consisting of intake and discharge pipes, a centrifugal pump, four valves, and a differential manometer were used in the model to reproduce maximum ebb and flood tidal flows in the harbor entrance.

11. An Automated Data Acquisition and Control System (ADACS) designed and constructed at WES (Figure 4) was used to secure wave-height

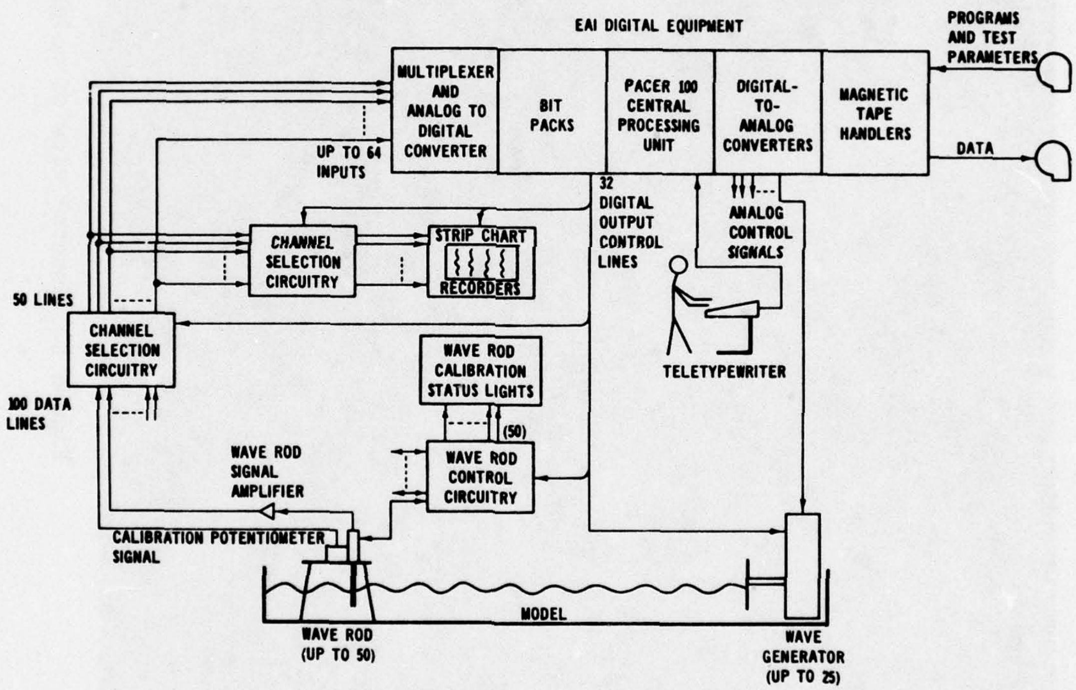

Figure 4. Automated Data Acquisition and Control System (ADACS)

data at selected locations in the model. Basically, through the use of a minicomputer, ADACS recorded onto magnetic tape the electrical output of parallel-wire resistance-type wave gages that measured the change in water-surface elevation with respect to time. The magnetic tape output

of ADACS was then analyzed to obtain the wave-height data.

12. A 2-ft (horizontal) solid layer of fiber wave absorber was placed around the inside perimeter of the model to damp any wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides to ensure proper formation of the wave train incident to the model contours.

Selection of Tracer Material

13. As previously discussed in paragraph 7, a fixed-bed model was constructed and a tracer material selected to determine qualitatively the degree of sediment transport for various improvement plans. As in previous WES investigations[7,8] the tracer material was chosen in accordance with the scaling relations of Noda[9] which indicate a relation or model law among the four basic scale ratios, i.e., the horizontal scale, λ ; the vertical scale, μ ; the sediment size ratio, η_D ; and the relative specific weight ratio, η_γ, (Figure 5).* These relations were determined experimentally using a wide range of wave conditions and beach materials and are valid mainly for the breaker zone.

14. Noda's scaling relations indicate that movable-bed models with scales in the vicinity of 1:75 (model to prototype) should be distorted (i.e., they should have different horizontal and vertical scales). Since the fixed-bed model of Newburyport Harbor was undistorted to allow accurate reproduction of sea and swell, wave-induced currents, and wave diffraction, the following procedure was used to select a tracer material. Using the prototype sand characteristics (median diameter, $D_{50} = 0.78$ mm ; specific gravity = 2.65) and assuming the horizontal scale to be in similitude (i.e., 1:75), the median diameter for a specific gravity of a given tracer material and the vertical scale were computed. The vertical scale then was assumed to be in similitude, and the tracer median diameter and horizontal scale were computed. This

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* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix A).

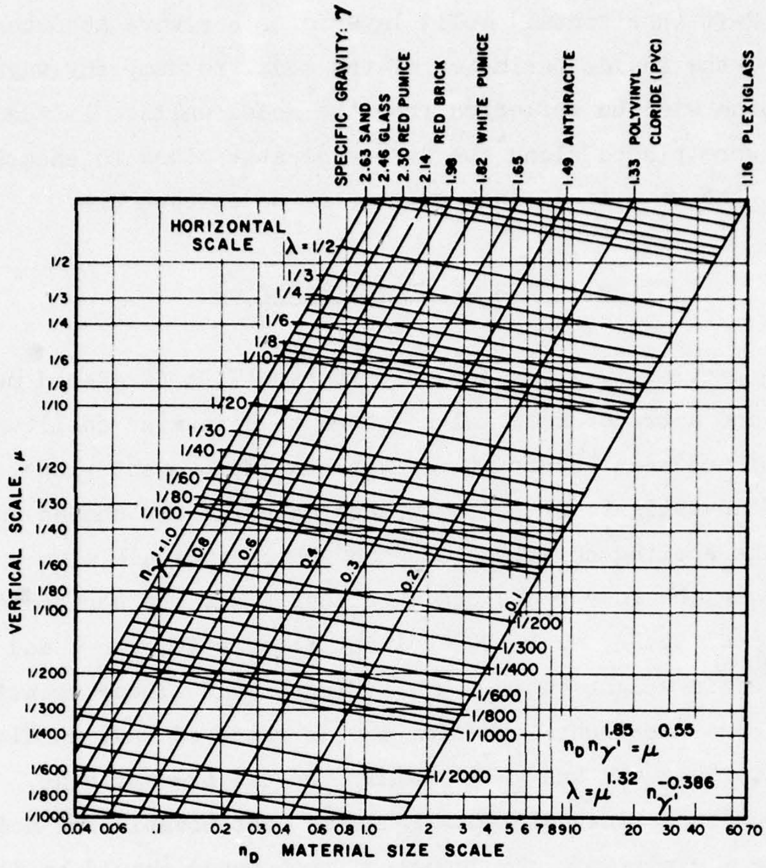

Figure 5. Graphical representation of model law (Reference 9)

resulted in a range of tracer material sizes for given specific gravities which could be used. A search was made of all movable-bed materials at WES, preliminary model tests were conducted, and a quantity of crushed coal (specific gravity = 1.30 , median diameter, D_{50} = 2.0 mm) was selected for the tracer tests.

PART III: TEST CONDITIONS AND PROCEDURES

Selection of Test Conditions

Still-water level

15. Still-water levels (swl's) for harbor wave action models are selected so that the various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include the refraction of waves in the harbor area, the overtopping of harbor structures by the waves, the reflection of wave energy from harbor structures, and the transmission of wave energy through porous structures. Since currents in the harbor affect wave characteristics, representative river discharges and tidal flows and their corresponding swl's must be accurately reproduced.

16. An evaluation of representative graphs of prototype current velocity versus time and water-surface elevation versus time produced swl's for maximum ebb and flood tidal flows. Maximum velocities for an ebb tidal flow condition occur at an swl of 0.0 ft. Similarly, for a flood tidal flow condition, maximum velocities occur at an swl of +2.9 ft. For slack water, mhw = +5.3 ft was chosen.

River and tidal flows

17. Maximum velocities obtained from the graphs mentioned in paragraph 16 were multiplied by their corresponding river cross-sectional areas to determine combined river and tidal flows in the harbor entrance. Maximum resultant combined freshwater (typical discharge of 8,200 cfs) and saltwater discharges were approximately 123,300 cfs for ebb conditions and 115,400 cfs for flood conditions representing model discharges of 2.53 cfs and 2.37 cfs, respectively.

Wave Dimensions and Directions

Factors influencing selection of test wave characteristics

18. In planning the testing program for a model investigation of harbor wave-action problems, it is necessary to select dimensions and

directions for the test waves that will allow a realistic test of proposed improvement plans and an accurate evaluation of the elements of the various proposals. Surface wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum wave that can be generated by a given storm depend on the wind speed, the length of time that a wind of a given speed continues to blow, the water distance (fetch) over which the wind blows, and the water depth. Selection of test wave conditions entails evaluation of such factors as:

<u>a</u>. Fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can attack the problem area.

<u>b</u>. Frequency of occurrence and duration of storm winds from the different directions.

<u>c</u>. Alignment, size, and relative geographic position of the navigation entrance to the harbor.

<u>d</u>. Alignments, lengths, and locations of various reflecting surfaces inside the harbor.

<u>e</u>. Refraction of waves caused by differentials in depth in the area seaward of the harbor, which may create either a concentration or diffusion of wave energy at the harbor site.

<u>Wave refraction</u>

19. When wind waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period. The most important transformations with respect to the selection of test wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. The change in wave height and direction can be determined by plotting refraction diagrams and calculating refraction coefficients. These diagrams are constructed by plotting the position of wave orthogonals (lines drawn perpendicular to wave crests) from deep water into shallow water. If it is assumed that the waves do not break and there is no lateral flow of energy, the ratio between the wave height in deep water, H_o, and

the wave height at any point in shallow water, H , is inversely proportional to the square root of the ratio of the corresponding orthogonal spacings b_o and b , or $H/H_o = K_s(b_o/b)^{1/2}$ where $(b_o/b)^{1/2}$ is the refraction coefficient K_r , and K_s is the shoaling coefficient. Thus, the refraction coefficient multiplied by the shoaling coefficient gives a conversion factor for the transfer of deepwater wave heights to shallow-water values. The shoaling coefficient, which is a function of wave length and water depth, can be obtained from Reference 10.

20. Wave-refraction diagrams for the Newburyport Harbor area were drawn for representative wave periods from the critical directions of approach. These diagrams represented the propagation of the wave fronts from deep water to shallow water (to the point of breaking). By positioning the wave generator to correspond to the wave front at -60 ft (the elevation of the wave generator pit), the refracted wave from the deepwater direction was accurately reproduced.

Prototype wave data and selection of test waves

21. Deepwater waves approaching Newburyport Harbor were obtained from surface marine observations.[11] These data (Table 1) represent the number of observations of deepwater waves approaching Newburyport Harbor from various directions. The refraction-shoaling analysis described in paragraph 19 was used to transfer the deepwater waves into shallow water (-60 ft) for use in the model. The shallow-water wave directions used in the model were the average directions of the refracted waves for the significant wave periods noted from each deepwater wave direction. The characteristics of the test waves selected for use in the model are shown in the following tabulation:

Deepwater Wave Direction	Selected Shallow-Water (-60 ft) Wave Test Direction	Selected Test Wave Period sec	Selected Test Wave Height ft
NE (39.5°)	51°	7	5,8,11
		11	6,9,15
		15	11

(Continued)

Deepwater Wave Direction	Selected Shallow-Water (-60 ft) Wave Test Direction	Selected Test Wave Period sec	Selected Test Wave Height ft
E (89.5°)	90°	7	4,8,12
		11	7,11,14,18
SE (139.5°)	122°	6	4,8,12
		9	4,8,12
		13	6

Analysis of Model Data

22. The relative merits of various plans tested were evaluated using (a) a comparison of wave heights at selected locations in the study area, (b) a comparison of current patterns and magnitudes, (c) movements of tracer material, and (d) visual observations and photographs. In the wave-height data analysis, the average height of the highest one third of the waves (significant wave height) at each gage location was selected. By using Keulegan's equation,[12] the reduction of wave heights in the model due to viscous bottom friction was calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel. This factor was multiplied by the measured value to obtain the adjusted wave height at a particular gage.

23. Since the main purpose of this model study was to develop a plan to alleviate wave-induced riverbank erosion on Plum Island, movement of tracer material was a prime concern. Tests of this type are of a qualitative nature, and no estimates of quantities transported are possible. Any appreciable loss of tracer material from the riverbank area, therefore, was considered a problem; and only those plans with very little or no loss of tracer material were considered as viable alternatives.

PART IV: TESTS AND RESULTS

Description of Tests

Existing conditions

24. Prior to tests of various improvement plans, comprehensive tests were performed for existing conditions (Plate 1). Wave-height data were obtained for various stations in the entrance channel for the test conditions listed in paragraph 21. Wave-induced current patterns and magnitudes and tracer patterns also were secured for representative waves from the three selected test directions.

Improvement plans

25. Wave height, current pattern and magnitude, and tracer tests were conducted for 13 improvement plan variations. These variations consisted of changes in the length of the north jetty, changes in the crown elevation of the north jetty, and addition of groins at two locations. Photographs of wave patterns with current patterns and magnitudes superimposed and photographs of tracer patterns were obtained for all major improvement plans. Brief descriptions of the improvement plans are presented in the following subparagraphs; dimensional details are presented in Plates 2-5.

- a. Plan 1 (Plate 2) consisted of raising the crown elevation of the existing north jetty from +8.3 ft (existing condition) to +11.0 ft.
- b. Plan 1A (Plate 2) consisted of raising the crown elevation of the north jetty to +14.0 ft.
- c. Plan 1B (Plate 2) consisted of raising the crown elevation of the north jetty to +17.0 ft.
- d. Plan 2 (Plate 3) consisted of a 1000-ft curved extension of the north jetty. This extension was constructed with a radius of 900 ft (prototype) and a crown elevation of +8.3 ft.
- e. Plan 2A (Plate 3) entailed the elements of plan 2 with the crown elevation raised to +11.0 ft.
- f. Plan 2B (Plate 3) involved the elements of plan 2A with 100 ft of the jetty extension removed.
- g. Plan 2C (Plate 3) entailed the elements of plan 2A with 200 ft of the jetty extension removed.

h. Plan 2D (Plate 3) involved the elements of plan 2A with 300 ft of the jetty extension removed.

i. Plan 2E (Plate 3) involved the elements of plan 2A with 400 ft of the jetty extension removed.

j. Plan 3 (Plates 4 and 5) consisted of an 850-ft-long groin (crown el +10 ft and designated the south groin) extending northward from the area of Plum Island being eroded with the elevation of the north jetty at +8.3 ft.

k. Plan 3A (Plates 4 and 5) entailed the elements of plan 3 with the north jetty elevation raised to +11.0 ft.

l. Plan 4 (Plates 6 and 7) involved the elements of plan 3 with the addition of an 820-ft-long groin (crown el +10 ft and designated the north groin) extending south from Salisbury Beach toward Plum Island Point. The crown elevation of the north jetty was +8.3 ft.

m. Plan 4A (Plates 6 and 7) entailed the elements of plan 4 with the north jetty elevation raised to +11.0 ft.

Wave-height tests

26. Wave-height tests for existing conditions and various improvement plans were conducted using test waves from one or more of the test directions listed in paragraph 21. As an expedient, tests involving certain proposed improvement plans were limited to one critical direction of approach (i.e., the NE deepwater direction). From previous tests, it became apparent that the NE direction was one of the most critical directions of wave approach for wave heights, current magnitudes, and depletion of tracer material. Existing conditions and plan 2B were tested comprehensively from all directions. Wave-height measurements were discontinued for the groin plans since these structures had no effect on wave heights in the navigation channel and the tracer tests were a more realistic method of evaluation. The wave-gage locations for existing conditions and each improvement plan are shown in Plates 1-3.

Current pattern and magnitude tests

27. Wave-induced current patterns and magntiudes were determined at selected locations by timing the progress of a dye tracer relative to a known distance on the model surface. These tests were conducted for existing conditions and the various improvement plans using representative test directions and test waves.

Tracer tests

28. Tracer tests were conducted for existing conditions and the various improvement plans using representative test directions and test waves. Before each test, tracer material was placed in lines across the channel, in the area of Plum Island experiencing erosion, and outside the north and south jetties as shown in Photos 12, 35, 51, and 68. For all tracer photographs, the water surface was disturbed to break up surface reflections. Any wave patterns discernible on these photographs are a result of this random disturbance and bear no relation to the test waves which resulted in the shoaling patterns shown.

Test Results

29. In evaluating test results, the relative merits of each plan were based primarily on an analysis of wave heights, current patterns and magnitudes, and/or the movement of tracer material and subsequent deposits. From this evaluation, the best improvement plans were selected.

Existing conditions

30. Wave heights for existing conditions are presented in Tables 2, 3, and 4 for waves approaching from the northeast, east, and southeast deepwater directions, respectively. The maximum wave height recorded for a maximum ebb flow condition (swl = 0.0 ft) was 14.8 ft at gage 2; for a maximum flood flow condition (swl = +2.9 ft), 14.1 ft at gage 2; and for slack water (swl = +5.3 ft), 17.7 ft at gage 2. Waves from the east and southeast deepwater directions tended to diffract around the south jetty to reach the area being eroded, thereby reducing their intensity somewhat. Waves from the northeast deepwater direction were able to travel between the jetties and reach this area unobstructed, resulting in extremely large wave heights. Substantial overtopping of and transmission through the north jetty were observed for the large waves from the northeast direction for slack water. Maximum wave heights recorded either at gage 4 or gage 6 (in the area of Plum Island being eroded) were 5.1, 8.2 and 11.4 ft for ebb, flood, and slack water, respectively.

31. Current patterns and magnitudes secured for existing conditions (Photos 1-11) reveal wave-induced currents frequently as high as 2.9 fps in the area being eroded for waves from the east and northeast deepwater directions. Current magnitudes for the southeast deepwater direction were comparatively small due to the sheltering effect of the south jetty. Ebb and flood tidal currents in the navigation channel were not greatly affected by the waves. Outside the jetties, wave-induced currents generally moved northward along the beach for waves from the southeast, southward along the beach for waves from the northeast, and away from the inlet in both directions for waves from the east.

32. Tracer movement (Photos 12-23), regardless of test direction, was basically into the inlet for flood flow and slack water with substantial movement to the northeast along the eroding shoreline of Plum Island. On the ebb tidal flow, an eddy formed in the area between Plum Island Point and the south jetty, resulting in continued northeasterly movement of tracer material along the eroding portion of Plum Island. The degree of tracer movement in the problem area was considerably more for the northeast test direction than for the east or southeast test directions. Considerable migration of tracer material through voids in the north jetty was observed for waves from the northeast. Outside the jetties, wave-induced tracer movement was northward along the beach for waves from the southeast, southward along the beach for waves from the northeast, and away from the inlet in both directions for waves from the east. Eddies at the shoreward terminus of both jetties caused shoaling deposits in these areas (outside entrance in the lee of downdrift jetty depending on wave direction).

Improvement plans

33. In determining the optimum crown elevation of the north jetty, only wave-height tests were conducted for plans 1, 1A, and 1B (Plate 2). Wave-height measurements obtained for these plans are tabulated in Table 5. All wave heights recorded immediately behind the north jetty (gages 1, 3, 8, and 11) and in the area of Plum Island where erosion is occurring (gages 4-7 and 12) were averaged for each gage and plotted as a function of the north jetty crown elevation (Plate 8). The curves

for each area were then combined to give an average curve from which an optimum crown elevation of +11.0 ft (plan 1) was selected. Compared with existing conditions, this plan reduced the average wave heights in the area where erosion is occurring by approximately 22 percent.

34. Wave-height measurements for plans 2 and 2A (Plate 3) are presented in Table 6. Plans 2 and 2A consist of a 1000-ft north jetty extension with crown elevations of +8.1 ft and +11.0 ft, respectively. When compared with existing conditions, plan 2 reduced wave heights by about 36 percent in the area of Plum Island where the most serious erosion is occurring. Considerable overtopping along the entire existing north jetty and extension was observed. Plan 2A reduced wave heights by approximately 52 percent. Overtopping was evident mainly along the jetty extension.

35. Wave-height measurements for plans 2B-2E (Plate 3) are presented in Tables 7-10. Plans 2B, 2C, 2D, and 2E correspond to 900-, 800-, 700-, and 600-ft-long north jetty extensions at a +11.0-ft crown elevation. Average wave heights for the same gages discussed in paragraph 33 were plotted as a function of jetty extension length and are presented in Plate 9. Removing 100 ft of the 1000-ft north jetty extension (plan 2B) did not significantly increase energy inside the harbor (still an average reduction of 48 percent over existing conditions). Compared with existing conditions, plans 2C, 2D, and 2E reduced wave heights 33, 37, and 27 percent, respectively.

36. Current patterns and magnitudes secured for plan 2B (Photos 24-34) reveal greatly reduced wave-induced currents in the area of Plum Island being eroded for waves from the east and northeast deepwater directions. Current magnitudes for the southeast deepwater direction showed no significant variation from existing conditions. Ebb and flood current velocities in the channel were relatively unaffected by the jetty extension; however, ebb currents were deflected slightly southward at the harbor entrance. Currents outside the jetties were the same as those discussed in paragraph 31.

37. Movement of tracer material for plan 2B (Photos 35-46) over the entire entrance channel area was less than that experienced for existing

conditions. For all waves, movement of tracer in the area of Plum Island being eroded was decreased substantially.

38. Wave and current patterns and current magnitudes for plans 3 (850-ft-long south groin with existing north jetty) and 3A (850-ft-long south groin with revised north jetty) are presented in Photos 47-50 and 56-59. Currents in the entrance channel area remained essentially unchanged for these plans. However, the large eddy predominant in the area of Plum Island being eroded was interrupted by this groin, thereby preventing the formation of strong longshore currents.

39. Tracer tests for plans 3 and 3A indicated that these plans effectively halted the erosion process on Plum Island and, in fact, trapped material entering the area (Photos 51-55 and 60-63). Tracer material seaward of the groin migrated into the shoreward terminus to form a fillet while tracer material in the lee of the groin moved very little. The higher crown elevation of the north jetty for plan 3A resulted in slightly less tracer movement and improved entrance channel wave conditions when compared with plan 3.

40. Wave patterns and current patterns and magnitudes for plans 4 (north and south groins with existing north jetty) and 4A (north and south groins with revised north jetty) are presented in Photos 64-67 and 73-76. The addition of the north groin did not signficantly alter the currents in the vicinity of the south groin. However, due to the restricted width of the channel between the end of the north groin and Plum Island, currents as high as 13 fps were observed in this area. Numerous eddies were observed in the lee of the north groin for both plans.

41. Tracer movement in the vicinity of the south groin for plans 4 and 4A (Photos 68-72 and 77-80) remained essentially unchanged from that of plans 3 and 3A. However, due to the large current velocities mentioned in the preceding paragraph, movement of tracer in the entrance channel was considerable indicating that severe erosion of the channel would occur in this area. Tracer indications were that the deep trench adjacent to the north jetty would shoal considerably.

Discussion of test results

42. Test results obtained for existing conditions (with moderate

to large incident waves) revealed rough and turbulent wave conditions in the entrance channel due to (a) waves breaking on the shoal across the harbor entrance, (b) waves diffracting around the jetties, and (c) waves overtopping the north jetty. Tracer tests indicated that the model accurately reproduced the general sediment patterns observed in the prototype (as evidenced by visual observations and aerial photographs).

43. A comparison of plans 1, 1A, and 1B with existing conditions indicated that plan 1 reduced the average wave heights in the area where erosion is occurring by approximately 22 percent. Plate 8 shows that increasing the crown elevation of the north jetty above +11.0 ft provided no additional benefit. At some gages, wave heights were actually higher for the higher crown elevations due to the fact that overtopping and/or transmitted waves no longer interfered with waves diffracted around the end of the north jetty.

44. Results of wave-height tests for plans 2 and 2A revealed that for both plans, wave heights in the area being eroded were decreased significantly. When compared with existing conditions, wave heights for plans 2 and 2A were reduced approximately 36 percent and 52 percent, respectively.

45. Compared with existing conditions, plans 2B, 2C, 2D, and 2E reduced wave heights 48, 33, 37, and 27 percent, respectively, in the vicinity of the erosion problem area. Wave heights measured for plan 2C (33 percent reduction) do not fit the curves shown in Plate 9 for plans 2A-2E. At first glance the data appear to be in error, but the fact that all gages are higher than expected for this plan makes this doubtful. A more likely explanation is that waves overtopping and diffracting around the end of the jetty extension combine to focus wave energy in this area for this particular jetty length. In any case, plan 2B appears to offer the most protection at the least cost of the jetty extensions tested.

46. Results of current and tracer tests for plan 2B, when compared with existing conditions, showed a marked reduction in current velocities and tracer movement in the area of Plum Island being eroded. Movement

of tracer in the entrance channel also was reduced due to the decreased turbulence of the water.

47. Plans 3 and 3A proved very effective in eliminating strong wave-generated currents and in trapping and retaining tracer material in the riverbank area of Plum Island being eroded. Plan 3A resulted in slightly less tracer movement and improved entrance channel wave conditions when compared with plan 3. Typical sections of the south groin are shown in Plate 5.

48. Though plans 4 and 4A retain tracer at the south groin, the large current velocities between the end of the north groin and Plum Island, the numerous eddies in the lee of the north groin, and the interactions between ebb currents and incoming waves all combine to create very hazardous entrance conditions. Indications are that the north groin could be subject to serious undermining. Typical sections of the north groin are shown in Plate 7.

PART V: CONCLUSIONS

49. Based on results of the three-dimensional model investigation reported herein, it is concluded that:

<u>a</u>. For moderate to large incident waves, existing conditions are characterized by turbulent wave conditions in the entrance channel and strong longshore currents in the area between the south jetty and Plum Island Point, resulting in continued northeasterly movement of tracer material along the eroding portion of Plum Island.

<u>b</u>. Of the improvement plans tested involving raising the north jetty crown elevation (plans 1-1B), plan 1 (crown elevation +11.0 ft) was selected as the optimum with respect to wave protection and construction costs.

<u>c</u>. Of the improvement plans tested involving the north jetty extension (plans 2-2E), plan 2B (900-ft extension) was selected as the optimum with respect to wave protection, prevention of erosion on Plum Island, and construction costs.

<u>d</u>. Of the south groin plans tested, plan 3A (north jetty crown elevation +11.0 ft) provided better wave protection than plan 3 (north jetty crown elevation +8.3 ft).

<u>e</u>. The plans tested involving both north and south groins (plans 4 and 4A) resulted in extremely large current velocities in the entrance channel, and might cause erosion of Plum Island and navigation problems.

<u>f</u>. Of the plans tested, plans 2B, 3, and 3A all provided adequate erosion protection for the northern end of Plum Island. Plan 3 requires the least volume of rock but does not improve entrance wave conditions. Plan 2B provides the optimum entrance wave conditions but requires the greatest volume of rock. Plan 3A offers adequate erosion protection while improving entrance wave conditions and appears to be the optimum plan with regard to protection provided and cost.

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TABLE 1

DEEPWATER WAVES APPROACHING NEWBURYPORT HARBOR FROM VARIOUS DIRECTIONS

WAVE HEIGHT* METRES	TOTAL OBSERVATIONS PER WAVE PERIOD, SEC 5	7	9	11	13	15	17	21	>21	TOTAL
					NORTHEAST					
0-1	348	32							19	399
1-2	366	342	78	16						802
2-3	69	102	37	34		6				248
3-4		3	51							54
4-5			2	17				20		39
5-6		10								10
6-7							10			10
7-8					2					2
TOTAL	783	489	168	67	2	6	10	20	19	1564
					EAST					
0-1	203	36	16						7	262
1-2	200	123	37	14						374
2-3	24	49	66	14						153
3-4	10	64	11	13				4		102
4-5				2						2
5-6			3							3
6-7			10							10
7-8										
TOTAL	437	272	143	46				4	7	909
					SOUTHEAST					
0-1	291	19							9	319
1-2	285	156	10		4					455
2-3	46	95	36		5					182
3-4	11	10	5	10						36
4-5		18	17	10						45
TOTAL	633	298	68	20	9				9	1037

* Wave-height and wave-period groupings include the lower but not the upper values.

TABLE 2

WAVE HEIGHTS FOR EXISTING CONDITIONS

FROM NORTHEAST DIRECTION

Test Wave Direction Deg	Test Wave Period Sec	Test Wave Height Ft	Wave Height, Ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
			SWL = 0.0 FT (MAXIMUM EBB)											
51	7.0	5.0	7.3	7.2	2.1	1.9	1.0	1.5	1.8	0.6	0.5	0.4	0.3	2.0
		8.0	8.6	5.6	2.7	3.0	2.0	1.4	3.6	1.0	1.0	0.7	0.5	3.3
		11.0	8.3	5.9	2.1	2.5	1.8	1.4	1.9	0.8	0.6	0.5	0.4	2.7
	11.0	6.0	8.9	10.4	1.9	4.4	2.2	2.6	3.6	1.0	0.9	0.6	0.5	5.4
		9.0	8.5	7.8	1.4	3.1	1.7	1.3	3.0	0.8	0.9	0.5	0.3	4.1
		15.0	10.4	8.6	2.1	3.6	2.5	2.2	2.2	1.0	0.9	0.5	0.5	3.3
	15.0	11.0	11.9	8.2	2.1	4.1	1.8	4.2	2.8	0.7	0.8	0.4	0.3	3.1
			SWL = +2.9 FT (MAXIMUM FLOOD)											
	7.0	5.0	6.3	7.1	2.5	3.4	1.5	2.3	2.6	1.0	1.2	0.5	0.5	3.4
		8.0	9.6	10.3	4.0	4.0	3.5	3.9	3.5	2.6	2.6	1.0	1.4	3.1
		11.0	10.7	11.5	7.2	3.5	3.1	3.2	2.7	3.7	2.5	1.2	1.6	3.3
	11.0	6.0	10.0	9.9	6.5	8.2	4.2	6.6	4.3	2.5	3.1	1.1	2.1	6.8
		9.0	8.1	6.0	9.4	4.9	3.2	5.0	5.0	2.8	2.4	1.3	1.7	5.5
		15.0	9.1	9.0	6.9	4.1	4.2	3.7	3.8	4.2	3.6	2.5	1.9	4.5
	15.0	11.0	8.8	12.7	6.2	4.4	3.8	6.0	5.2	3.6	3.9	1.7	2.2	5.4
			SWL = +5.3 FT (SLACK WATER)											
	7.0	5.0	5.3	7.3	1.3	3.9	1.1	3.1	3.5	2.0	2.1	0.5	0.7	3.3
		8.0	8.6	9.6	3.6	5.5	4.0	3.0	3.7	1.6	2.4	0.7	1.3	6.1
		11.0	11.9	9.1	4.8	7.5	6.1	4.7	5.9	2.2	2.6	0.9	1.4	8.7
	11.0	6.0	9.4	10.2	3.3	11.4	3.7	4.9	6.0	1.9	1.6	0.8	0.8	7.3
		9.0	11.2	8.6	5.1	9.7	9.8	5.6	5.9	2.9	2.4	1.0	1.4	7.5
		15.0	12.2	9.9	7.8	8.9	9.2	7.2	8.1	3.3	3.0	1.1	1.8	8.3
	15.0	11.0	8.1	14.4	4.3	8.1	8.0	8.9	5.0	3.4	2.6	1.1	1.5	6.3

TABLE 3

WAVE HEIGHTS FOR EXISTING CONDITIONS

FROM EAST DIRECTION

Test Wave Direction DEG	Test Wave Period SEC	Test Wave Height FT	Wave Height, FT Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
			SWL = 0.0 FT (MAXIMUM EBB)											
90	7.0	4.0	5.5	8.2	2.8	1.8	1.4	3.2	3.7	0.5	0.7	0.4	0.4	1.6
		8.0	12.3	9.8	3.5	3.0	2.7	2.9	4.0	1.0	1.2	0.7	0.5	5.6
		12.0	7.6	10.0	3.6	2.4	2.6	4.7	4.2	1.6	1.8	0.7	0.6	3.2
	11.0	7.0	9.4	7.5	2.8	2.9	2.5	5.1	3.6	1.1	1.2	0.7	0.6	4.1
		11.0	8.5	12.8	5.3	2.9	2.6	4.6	5.8	1.4	1.5	0.8	0.7	3.2
		14.0	7.8	14.8	4.0	2.2	2.4	2.6	3.8	1.1	1.1	0.6	0.6	2.7
		18.0	9.2	9.4	2.9	2.3	1.1	2.2	3.0	0.9	1.1	0.8	0.6	2.5
			SWL = +2.9 FT (MAXIMUM FLOOD)											
	7.0	4.0	5.5	6.0	2.6	1.6	3.9	4.4	5.0	1.5	2.4	0.7	1.5	1.8
		8.0	11.3	9.7	6.3	2.4	5.8	5.1	6.5	4.1	5.1	2.2	3.5	4.1
		12.0	10.4	10.4	6.4	3.1	5.3	6.2	7.1	2.8	4.6	1.8	2.9	4.4
	11.0	7.0	13.1	14.1	8.9	5.2	5.7	6.1	5.9	2.6	3.7	2.6	2.1	4.4
		11.0	11.7	11.9	7.6	4.6	3.3	6.4	7.2	2.4	3.3	1.8	2.2	3.9
		14.0	11.3	10.0	6.9	4.4	2.7	5.9	7.0	2.6	3.2	1.6	2.6	5.0
		18.0	9.3	12.0	8.4	3.3	3.4	6.3	6.8	3.6	4.8	2.0	3.1	4.7
			SWL = +5.3 FT (SLACK WATER)											
	7.0	4.0	3.3	4.9	4.2	0.4	2.6	3.7	4.6	0.9	2.1	0.4	1.1	2.0
		8.0	10.4	13.9	2.9	2.5	9.8	5.7	7.8	2.0	5.0	1.9	3.7	3.5
		12.0	10.7	9.3	8.1	3.5	3.7	6.0	8.1	2.0	5.4	1.6	3.4	5.5
	11.0	7.0	10.3	15.8	8.0	8.2	12.7	7.4	8.7	2.4	3.4	2.1	3.5	7.8
		11.0	11.6	17.0	8.8	5.6	5.0	6.9	8.2	2.8	4.5	1.6	2.7	5.3
		14.0	11.8	15.8	8.5	3.5	4.0	7.3	7.0	3.0	5.1	1.2	2.6	4.3
		18.0	11.2	17.7	8.3	4.7	4.1	6.1	7.1	3.0	4.6	1.3	2.3	5.2

TABLE 4

WAVE HEIGHTS FOR EXISTING CONDITIONS

FROM SOUTHEAST DIRECTION

Test Wave Direction DEG	Test Wave Period SEC	Test Wave Height FT	Wave Height, FT Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
			SWL = 0.0 FT (MAXIMUM EBB)											
122	6.0	4.0	5.9	6.8	3.5	1.5	1.1	1.6	2.1	1.3	0.9	0.6	0.7	2.0
		8.0	8.7	6.8	2.5	1.7	1.1	1.3	2.2	0.9	0.6	0.5	0.6	1.9
		12.0	9.9	6.2	1.8	0.8	0.6	1.0	1.4	0.8	0.6	0.5	0.5	1.4
	9.0	4.0	7.0	9.8	4.0	1.5	2.4	3.4	5.1	1.7	1.8	0.8	0.8	3.1
		8.0	12.1	5.6	2.6	1.3	1.5	2.1	2.4	0.8	0.8	0.3	0.4	2.2
		12.0	9.3	5.8	1.8	1.1	0.9	1.7	1.7	0.5	0.5	0.4	0.4	1.3
	13.0	6.0	12.6	6.6	3.5	2.2	3.3	4.3	4.7	1.0	1.2	0.8	0.6	2.5
			SWL = +2.9 FT (MAXIMUM FLOOD)											
	6.0	4.0	4.8	1.1	1.2	0.8	0.8	0.8	0.8	0.6	0.4	0.4	0.3	0.9
		8.0	11.1	7.2	1.9	3.2	1.5	1.7	1.7	0.6	0.9	0.6	0.5	3.5
		12.0	9.2	7.2	4.1	3.5	2.4	2.2	2.4	1.4	1.5	0.9	1.0	3.2
	9.0	4.0	9.2	3.4	2.2	1.4	1.6	1.8	1.5	0.6	0.7	0.4	0.4	2.0
		8.0	9.9	8.5	6.0	5.2	2.5	3.5	3.2	2.1	2.7	1.1	1.6	5.8
		12.0	9.3	6.6	3.8	5.1	2.3	2.6	2.5	1.1	1.4	0.7	0.8	5.4
	13.0	6.0	7.6	5.4	3.3	3.2	2.0	2.1	1.7	1.7	1.9	0.8	1.4	2.7
			SWL = +5.3 FT (SLACK WATER)											
	6.0	4.0	5.3	1.3	2.7	0.6	0.7	1.2	1.1	0.5	1.3	0.3	0.7	0.4
		8.0	9.6	8.4	4.1	1.7	3.0	2.6	2.7	1.5	2.1	0.5	1.6	2.9
		12.0	13.4	8.7	5.9	3.2	3.3	4.6	3.9	2.2	3.2	0.6	2.0	5.0
	9.0	4.0	8.5	3.1	2.0	1.5	4.1	1.5	2.4	1.3	0.9	0.7	0.9	1.9
		8.0	11.1	5.8	6.2	2.5	4.2	4.6	3.4	1.9	2.4	1.1	1.4	3.4
		12.0	14.1	8.2	4.8	3.0	3.8	3.9	4.0	1.8	1.9	1.0	1.4	3.6
	13.0	6.0	14.0	8.2	3.2	4.1	3.5	3.5	3.4	2.4	2.4	1.0	1.7	3.6

TABLE 5

WAVE HEIGHTS FOR PLANS 1, 1A, AND 1B FROM NORTHEAST DIRECTION

SWL = +5.3 FT (SLACK WATER)

Test Wave			Wave Height, ft											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
			PLAN 1											
51	7.0	5.0	1.4	5.8	1.0	3.2	1.9	1.6	1.5	0.6	1.4	0.3	0.7	2.4
		8.0	1.5	10.5	2.9	4.9	2.9	2.3	2.3	1.1	2.1	0.3	1.0	4.4
		11.0	5.6	10.1	6.2	3.4	5.3	5.0	4.5	1.8	2.6	0.8	2.1	4.9
	11.0	6.0	2.7	11.7	3.8	10.7	5.7	3.0	2.4	1.4	1.5	0.6	1.9	7.8
		9.0	3.7	15.6	5.6	7.1	8.8	6.0	4.8	2.6	2.7	1.3	2.0	7.8
		15.0	3.8	12.5	4.7	8.2	8.3	4.9	3.4	1.4	2.1	1.3	1.7	10.4
	15.0	4.7	8.9	14.2	3.1	5.8	5.4	5.5	7.0	1.8	2.3	0.7	2.2	6.0
			PLAN 1A											
	7.0	5.0	1.5	6.0	0.7	3.3	1.3	2.6	2.3	1.2	1.4	0.3	0.8	2.7
		8.0	2.1	10.1	3.7	6.0	3.8	3.3	3.1	1.5	2.3	0.6	1.4	6.3
		11.0	6.3	9.2	4.3	3.7	5.8	4.4	3.6	1.0	1.7	0.7	1.3	6.2
	11.0	6.0	3.6	10.1	4.1	6.6	4.2	4.3	2.6	1.4	2.1	0.7	1.7	7.4
		9.0	4.2	12.6	4.5	7.9	7.1	5.4	4.0	1.5	3.0	0.9	2.0	8.5
		15.0	4.7	9.0	4.9	6.0	6.6	5.0	5.2	1.3	2.8	0.9	2.3	9.1
	15.0	11.0	8.6	9.4	5.6	4.1	6.3	5.1	3.8	2.5	2.8	1.3	3.6	4.6
			PLAN 1B											
	7.0	5.0	6.1	6.2	2.7	2.4	3.8	2.8	2.6	1.9	2.7	0.7	2.0	3.5
		8.0	1.4	5.9	1.2	3.1	1.4	2.2	0.7	0.6	1.3	0.3	1.2	2.4
		11.0	1.6	9.4	2.8	5.0	3.2	2.5	2.4	1.1	2.0	0.4	1.3	4.3
	11.0	6.0	4.9	10.5	5.1	5.8	5.6	5.3	4.0	1.8	2.6	1.0	2.0	8.5
		9.0	2.6	10.0	3.7	10.3	6.4	2.9	3.2	1.6	1.2	0.8	2.3	7.2
		15.0	4.1	12.4	6.2	10.5	13.2	6.4	4.6	2.7	2.2	1.4	2.5	8.4
	15.0	11.0	8.9	12.5	3.7	4.1	5.6	5.9	3.5	2.3	2.1	0.9	2.6	4.5

TABLE 6

WAVE HEIGHTS FOR PLANS 2 AND 2A FROM NORTHEAST DIRECTION

SWL = +5.3 FT (SLACK WATER)

Test Wave Direction DEG	Test Wave Period SEC	Test Wave Height FT	Wave Height, FT Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
							PLAN 2							
51	7.0	5.0	1.2	2.1	1.6	2.0	1.1	1.2	1.9	0.9	0.8	0.3	1.0	2.3
		8.0	2.0	4.0	2.3	2.8	1.8	2.0	3.5	1.0	1.2	0.4	0.9	3.5
		11.0	4.6	7.9	2.8	3.4	2.6	2.4	2.8	1.7	1.4	0.6	1.3	5.3
	11.0	9.0	4.7	7.5	3.0	8.4	2.6	3.5	5.2	1.5	1.4	0.9	2.1	7.3
		6.0	3.9	5.7	2.1	6.2	2.3	3.6	5.9	1.1	1.1	0.9	2.0	5.7
		15.0	4.5	4.9	5.7	8.7	2.9	4.2	4.9	1.8	1.9	0.7	1.9	6.4
	15.0	11.0	3.5	5.8	4.9	5.4	5.3	5.4	3.7	2.5	1.8	1.0	3.4	6.6
							PLAN 2A							
	7.0	5.0	0.8	2.3	1.1	2.0	1.3	1.2	1.9	0.9	0.6	0.4	0.9	2.2
		8.0	1.5	4.3	1.9	2.9	2.1	2.8	2.8	0.9	0.9	0.5	1.3	3.0
		11.0	2.3	5.1	1.7	3.0	2.3	2.2	1.8	0.9	0.9	0.5	1.4	3.4
	11.0	6.0	1.9	3.0	1.9	4.5	1.9	2.8	4.2	0.8	1.1	0.6	1.2	3.6
		9.0	2.6	5.8	2.9	7.7	2.4	3.1	4.1	1.1	1.4	0.6	1.1	5.0
		15.0	3.6	4.0	3.2	5.6	3.6	3.2	2.8	1.5	1.6	1.0	1.6	4.9
	15.0	11.0	3.8	4.3	3.7	4.0	4.6	2.4	2.7	1.2	1.9	0.9	2.8	2.8

TABLE 7

WAVE HEIGHTS FOR PLANS 2B, AND 2C FROM NORTHEAST DIRECTION

SWL = +5.3 FT (SLACK WATER)

Test Wave Direction DEG	Test Wave Period SEC	Test Wave Height FT	Wave Height, FT GAGE 1	GAGE 2	GAGE 3	GAGE 4	GAGE 5	GAGE 6	GAGE 7	GAGE 8	GAGE 9	GAGE 10	GAGE 11	GAGE 12
							PLAN 2B							
51	7.0	5.0	0.6	2.0	0.8	2.0	1.2	0.6	1.9	0.5	0.7	0.2	0.8	1.8
		8.0	1.0	2.8	1.6	2.7	1.5	2.4	2.2	0.6	0.7	0.4	0.7	2.4
		11.0	3.0	5.1	2.1	2.4	2.0	2.0	2.8	1.4	1.4	0.6	1.6	2.5
	11.0	6.0	2.7	4.3	2.1	4.3	2.8	4.4	4.2	1.4	1.1	0.6	1.5	3.4
		9.0	3.7	6.8	2.7	5.8	3.0	5.0	3.4	1.8	1.3	0.6	1.5	5.1
		15.0	3.9	6.1	3.5	5.4	3.0	4.4	4.6	1.6	1.3	0.7	1.8	6.3
	15.0	11.0	5.1	5.9	4.9	4.7	5.2	3.3	3.6	2.2	2.0	1.0	3.5	3.5
							PLAN 2C							
	7.0	5.0	0.9	1.2	1.0	1.5	0.9	1.5	2.7	0.8	0.7	0.4	0.8	1.3
		8.0	1.6	2.1	1.8	2.8	1.6	2.8	2.8	0.6	0.8	0.5	1.0	2.7
		11.0	3.9	7.2	2.8	4.0	3.6	4.1	3.9	1.5	1.4	1.0	1.5	6.2
	11.0	6.0	2.9	5.4	2.2	4.7	3.6	4.3	4.9	1.3	0.8	0.5	1.4	4.3
		9.0	3.1	8.8	2.7	7.1	5.6	5.6	4.9	1.5	1.4	0.8	1.4	5.6
		15.0	3.2	7.9	3.0	6.3	5.8	6.2	4.9	1.6	1.9	1.2	2.1	5.5
	15.0	11.0	5.1	7.5	3.5	5.7	4.1	5.7	3.8	2.3	1.7	1.0	3.1	3.9

TABLE 7 (CONTINUED)

WAVE HEIGHTS FOR PLANS 2D, AND 2E FROM NORTHEAST DIRECTION

SWL = +5.3 FT (SLACK WATER)

Test Wave Direction DEG	Test Wave Period SEC	Test Wave Height FT	Wave Height, FT Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
							PLAN 2D							
51	7.0	5.0	0.9	2.2	1.3	1.4	0.9	1.7	3.0	1.0	0.9	0.6	0.9	1.5
		8.0	1.6	4.2	1.5	1.9	1.4	3.4	3.4	0.9	0.8	0.6	0.9	1.4
		11.0	2.8	7.5	2.8	3.6	2.7	2.1	2.8	1.8	1.6	0.8	2.0	5.2
	11.0	6.0	2.6	5.6	2.0	5.6	3.5	4.7	4.1	1.1	0.7	0.5	1.2	5.1
		9.0	2.9	10.5	2.7	7.4	6.5	7.7	3.9	1.7	1.8	1.0	1.7	6.5
		15.0	3.2	8.5	3.1	6.1	4.5	6.4	4.6	1.5	1.3	1.0	2.2	5.7
	15.0	11.0	6.0	8.7	5.1	5.0	4.7	4.2	4.4	2.2	2.8	1.2	3.4	4.2
							PLAN 2E							
	7.0	5.0	1.0	3.5	1.6	1.9	0.7	2.2	3.5	1.1	1.0	0.8	0.8	2.4
		8.0	1.5	6.6	1.5	2.4	2.1	3.9	4.4	1.1	0.9	0.9	0.9	2.1
		11.0	4.2	7.9	4.3	5.4	5.0	3.0	3.6	1.9	1.9	1.1	2.0	8.5
	11.0	6.0	2.1	7.4	2.1	5.5	3.6	6.3	3.7	2.1	1.1	0.8	1.8	5.4
		9.0	4.0	9.8	4.8	7.6	5.2	7.6	3.8	1.5	1.6	1.0	1.9	6.8
		15.0	4.6	9.1	4.8	7.2	7.9	7.4	3.8	2.0	1.9	1.2	1.8	5.3
	15.0	11.0	5.7	11.4	5.1	5.6	4.6	7.3	4.1	2.3	2.3	1.2	3.5	4.4

TABLE 8

WAVE HEIGHTS FOR PLAN 2B

FROM NORTHEAST DIRECTION

Test Wave Direction DEG	Test Wave Period SEC	Test Wave Height FT	Wave Height, FT Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
			SWL = 0.0 FT (MAXIMUM EBB)											
51	7.0	5.0	1.3	1.5	1.8	0.4	0.7	0.4	1.2	0.3	0.3	0.2	0.4	0.8
		8.0	1.5	1.9	1.9	0.8	0.8	0.9	1.9	0.5	0.5	0.3	0.5	1.1
		11.0	0.9	1.9	1.0	0.7	0.8	1.0	1.0	0.3	0.2	0.2	0.3	0.8
	11.0	6.0	1.5	2.0	0.9	0.8	0.5	1.5	1.4	0.3	0.3	0.2	0.5	1.2
		9.0	1.0	2.1	1.0	1.0	0.6	2.4	2.0	0.3	0.4	0.3	0.4	0.7
		15.0	1.4	2.8	1.0	1.5	1.1	2.1	1.5	0.3	0.4	0.3	0.5	1.7
	15.0	11.0	1.4	2.1	1.2	2.0	1.3	1.9	1.4	0.4	0.3	0.3	0.5	1.6
			SWL = +2.9 FT (MAXIMUM FLOOD)											
	7.0	5.0	1.4	2.7	0.7	2.6	1.4	1.6	1.3	0.4	0.4	0.3	0.7	2.6
		8.0	2.2	5.3	1.8	3.1	2.3	1.6	1.6	1.2	0.5	0.4	1.1	2.3
		11.0	2.8	6.9	1.5	2.7	1.5	1.1	0.8	0.7	0.4	0.4	1.0	2.4
	11.0	6.0	2.3	5.5	2.0	2.9	2.6	2.9	1.5	1.0	0.6	0.3	1.5	2.6
		9.0	3.8	6.9	2.6	3.0	2.0	2.7	1.4	0.8	0.4	0.4	1.2	2.6
		15.0	5.1	8.5	3.0	2.7	2.5	1.7	1.6	0.9	0.6	0.4	1.1	2.5
	15.0	11.0	4.2	6.5	2.0	3.9	3.1	2.5	1.4	1.0	0.7	0.6	1.1	3.2
			SWL = +5.3 FT (SLACK WATER)											
	7.0	5.0	0.6	2.0	0.8	2.0	1.2	0.6	1.9	0.5	0.7	0.2	0.8	1.8
		8.0	1.0	2.8	1.6	2.7	1.5	2.4	2.2	0.6	0.7	0.4	0.7	2.4
		11.0	3.0	5.1	2.1	2.4	2.0	2.0	2.8	1.4	1.4	0.6	1.6	2.5
	11.0	6.0	2.7	4.3	2.1	4.3	2.8	4.4	4.2	1.4	1.1	0.6	1.5	3.4
		9.0	3.7	6.8	2.7	5.8	3.0	5.0	3.4	1.8	1.3	0.6	1.5	5.1
		15.0	3.9	6.1	3.5	5.4	3.0	4.4	4.6	1.6	1.3	0.7	1.8	6.3
	15.0	11.0	5.1	5.9	4.9	4.7	5.2	3.3	3.6	2.2	2.0	1.0	3.5	3.5

TABLE 9

WAVE HEIGHTS FOR PLAN 2B

FROM EAST DIRECTION

Test Wave Direction DEG	Test Wave Period SEC	Test Wave Height FT	Wave Height, FT Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
SWL = 0.0 FT (MAXIMUM EBB)														
90	7.0	4.0	1.6	3.8	1.6	1.0	0.4	0.9	2.0	0.4	0.6	0.3	0.6	1.2
		8.0	2.9	5.1	1.7	0.9	0.8	1.0	2.1	0.5	0.4	0.3	0.8	1.2
		12.0	2.3	3.4	1.6	0.9	0.6	1.3	1.8	0.4	0.5	0.3	0.6	0.9
	11.0	7.0	2.1	4.9	2.0	0.9	1.6	1.7	3.7	0.4	0.7	0.3	0.7	1.4
		11.0	2.5	3.4	1.7	1.4	1.0	1.5	2.4	0.4	0.7	0.3	0.7	1.3
		14.0	3.1	4.2	2.5	1.5	1.8	1.7	2.8	0.6	0.9	0.4	0.8	1.7
		18.0	4.0	5.1	3.1	1.4	1.8	1.6	3.3	0.7	1.0	0.4	1.7	1.3
SWL = +2.9 FT (MAXIMUM FLOOD)														
	7.0	4.0	1.6	3.5	1.9	1.8	2.2	1.0	1.3	0.8	0.8	0.3	1.3	1.5
		8.0	5.1	4.6	2.9	3.6	3.4	3.0	4.3	2.3	2.0	1.1	2.2	3.0
		12.0	3.3	5.7	2.4	3.6	3.2	2.6	2.8	1.6	1.3	0.6	2.2	3.4
	11.0	7.0	3.5	4.6	3.8	3.9	5.1	3.6	2.5	1.4	1.2	0.8	2.5	3.6
		11.0	2.4	3.8	2.6	3.5	3.2	2.4	1.6	0.9	0.9	0.5	1.6	2.8
		14.0	2.8	3.4	1.8	3.6	2.9	1.8	1.9	0.9	0.7	0.6	1.4	3.5
		18.0	4.0	4.7	3.1	6.4	4.7	2.5	2.7	1.3	1.3	0.9	2.7	5.7
SWL = +5.3 FT (SLACK WATER)														
	7.0	4.0	1.2	3.7	3.1	1.3	1.8	2.0	2.2	0.7	0.8	0.4	0.9	2.5
		8.0	3.7	10.3	5.4	3.5	4.4	5.2	5.1	2.0	3.3	1.0	2.1	5.4
		12.0	2.7	6.8	4.5	2.6	3.0	5.7	4.6	2.0	2.2	0.8	2.1	4.4
	11.0	7.0	7.3	8.4	8.1	2.4	6.2	6.9	9.2	2.0	4.0	1.8	2.6	4.5
		11.0	7.1	8.9	6.9	2.7	5.0	5.0	6.2	1.5	2.7	1.3	2.2	3.3
		14.0	5.6	7.5	5.9	2.8	4.3	4.7	6.5	2.2	3.1	1.1	2.5	3.3
		18.0	5.2	8.5	5.5	2.5	4.3	4.5	5.1	2.1	2.7	1.1	2.5	2.8

TABLE 10

WAVE HEIGHTS FOR PLAN 2B

FROM SOUTHEAST DIRECTION

TEST WAVE DIRECTION DEG	TEST WAVE PERIOD SEC	TEST WAVE HEIGHT FT	WAVE HEIGHT, FT GAGE 1	GAGE 2	GAGE 3	GAGE 4	GAGE 5	GAGE 6	GAGE 7	GAGE 8	GAGE 9	GAGE 10	GAGE 11	GAGE 12
			SWL = 0.0 FT (MAXIMUM EBB)											
122	6.0	4.0	2.8	3.7	1.9	0.4	0.3	0.5	0.8	0.4	0.3	0.3	1.5	0.7
		8.0	2.3	3.5	1.5	0.5	0.3	0.8	0.8	0.4	0.4	0.2	1.3	0.8
		12.0	1.8	4.7	1.4	0.6	0.3	0.6	0.7	0.4	0.4	0.4	1.0	0.7
	9.0	4.0	4.6	5.6	1.6	0.9	0.7	1.1	1.7	0.5	0.5	0.3	0.6	1.9
		8.0	3.2	4.1	1.8	1.0	0.9	2.0	2.8	0.5	0.7	0.3	0.6	1.9
		12.0	2.1	4.3	1.5	0.6	0.6	1.2	1.5	0.5	0.4	0.3	0.6	0.9
	13.0	6.0	2.4	3.5	1.8	1.3	1.3	1.9	2.1	0.5	0.6	0.3	0.8	1.2
			SWL = +2.9 FT (MAXIMUM FLOOD)											
	6.0	4.0	1.5	1.5	0.7	0.7	0.4	0.3	0.3	0.2	0.2	0.1	0.4	0.8
		8.0	1.9	3.5	1.3	1.7	1.1	0.4	0.5	0.4	0.3	0.3	1.0	1.8
		12.0	2.8	6.7	2.5	3.4	1.7	1.2	1.0	0.7	0.4	0.5	2.0	3.6
	9.0	4.0	2.2	3.9	0.5	1.2	1.0	0.4	0.4	0.4	0.2	0.2	0.4	1.2
		8.0	4.4	7.1	2.2	5.1	1.9	1.0	1.0	0.8	0.6	0.4	1.5	3.7
		12.0	4.3	6.0	2.2	4.2	1.9	1.0	1.1	0.8	0.7	0.4	1.1	3.5
	13.0	6.0	3.4	6.6	2.3	3.1	1.7	1.2	1.5	1.1	0.5	0.6	1.6	3.6
			SWL = +5.3 FT (SLACK WATER)											
	6.0	4.0	2.2	1.5	1.8	0.5	0.9	0.9	0.4	0.3	0.4	0.2	0.3	0.6
		8.0	4.2	9.3	2.3	1.5	2.4	1.7	2.3	0.9	1.9	0.5	1.2	2.3
		12.0	6.4	8.6	3.5	2.8	2.3	3.1	3.6	1.8	3.0	0.7	2.0	3.4
	9.0	4.0	2.1	4.7	1.9	1.4	2.4	1.9	1.3	1.0	0.9	0.6	0.9	2.4
		8.0	7.2	10.5	4.7	2.4	2.5	2.7	3.6	1.6	1.8	1.1	2.7	2.3
		12.2	7.0	8.7	4.7	2.4	2.5	3.0	2.9	2.2	1.8	1.0	2.7	2.8
	13.0	6.0	3.9	7.4	3.5	2.4	1.8	2.7	2.3	1.7	1.8	0.9	1.8	2.4

Photo 1. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 7-sec, 8-ft waves from northeast for maximum ebb

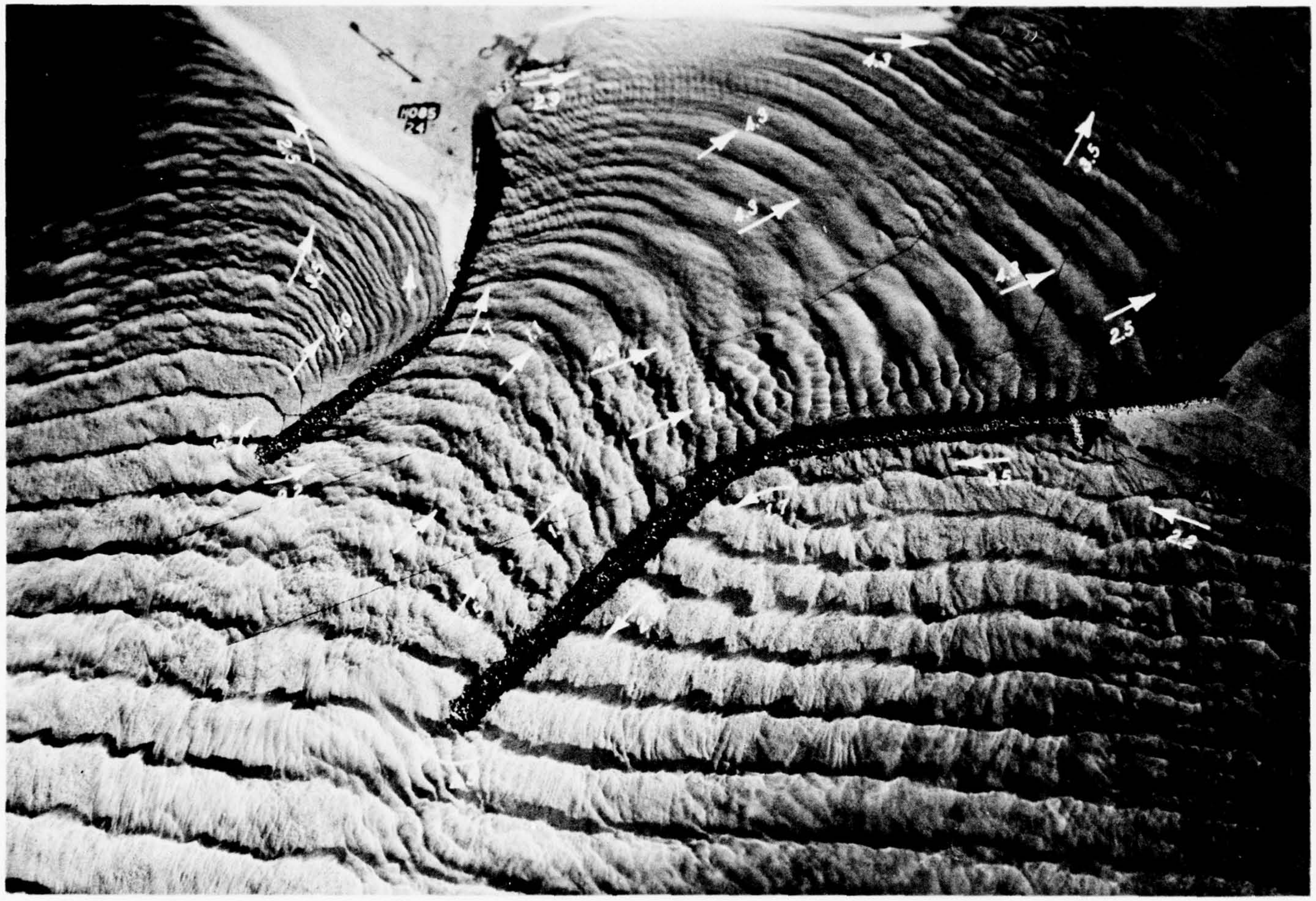

Photo 2. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 7-sec, 8-ft waves from northeast for maximum flood

Photo 3. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 7-sec, 8-ft waves from northeast for slack water

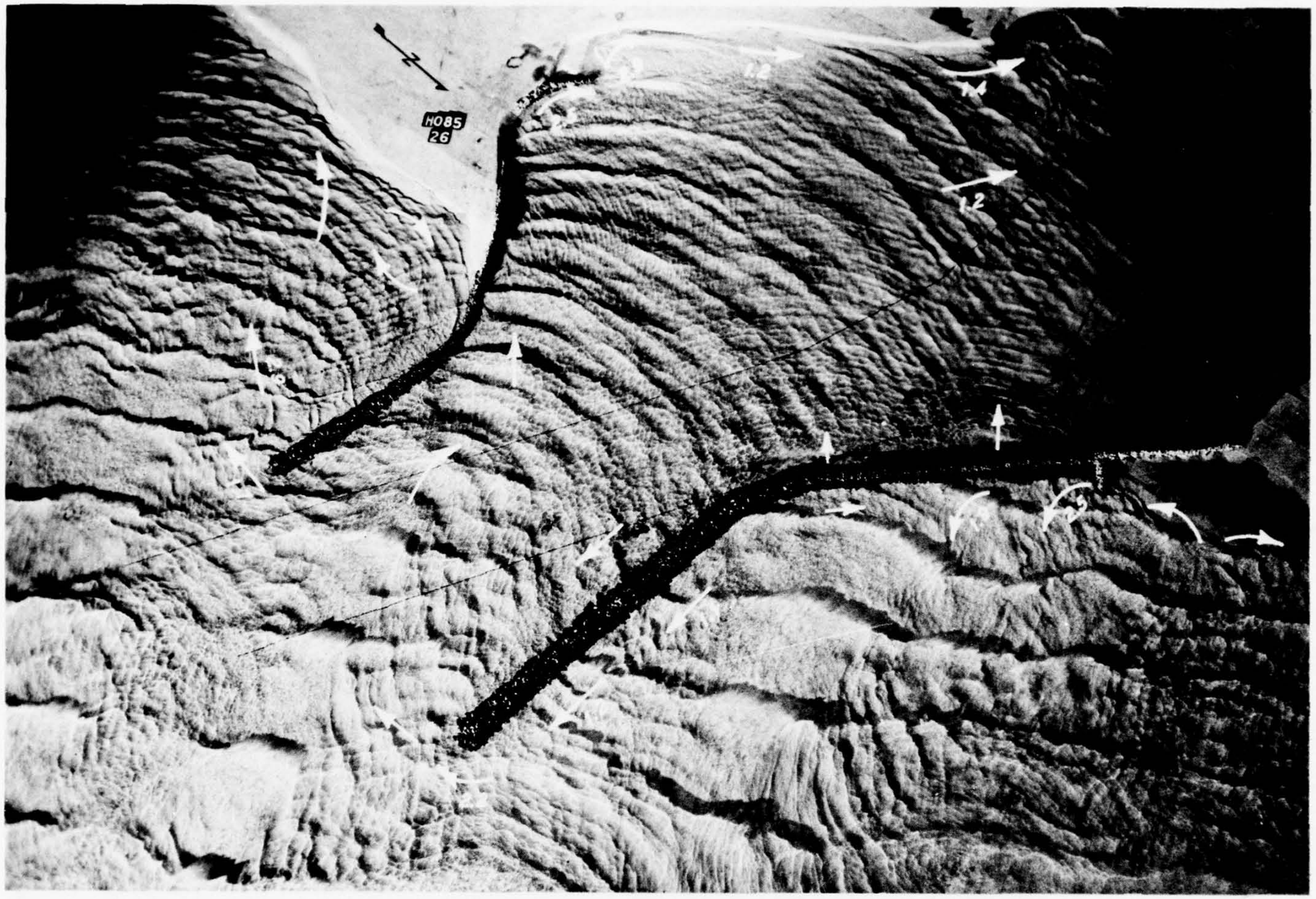

Photo 4. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 9-ft waves from northeast for slack water

Photo 5. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 7-sec, 8-ft waves from east for maximum ebb

Photo 6. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 7-sec, 8-ft waves from east for maximum flood

Photo 7. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 7-sec, 8-ft waves from east for slack water

Photo 8. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 14-ft waves from east for slack water

Photo 9. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 9-sec, 8-ft waves from southeast for maximum ebb

Photo 10. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 9-sec, 8-ft waves from southeast for maximum flood

Photo 11. Typical wave and current patterns and current magnitudes (prototype feet per second) for existing conditions; 9-sec, 8-ft waves from southeast for slack water

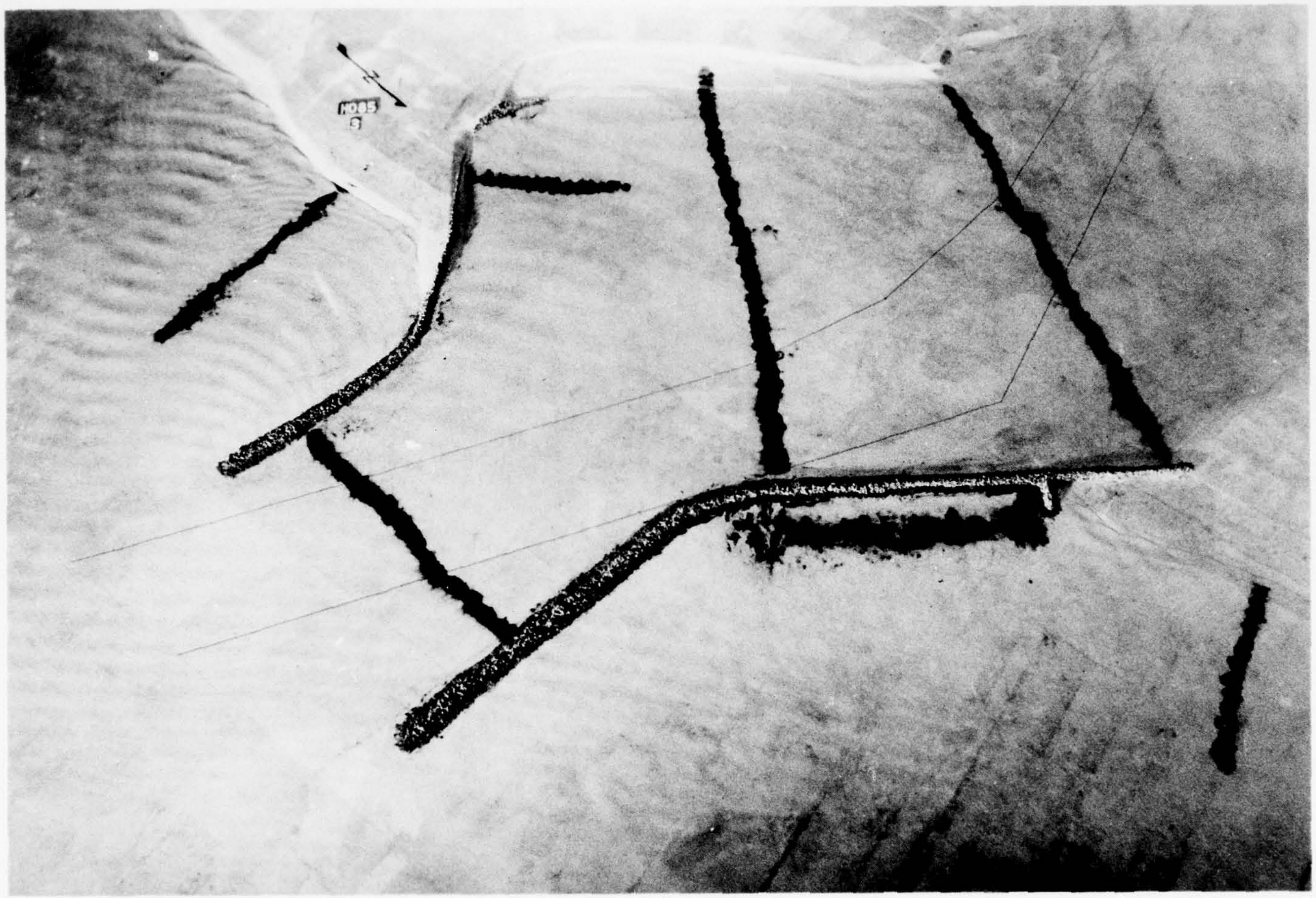

Photo 12. Tracer placement for existing conditions

Photo 13. Typical tracer movement for existing conditions resulting from 7-sec, 8-ft waves from northeast for maximum ebb

Photo 14. Typical tracer movement for existing conditions resulting from 7-sec, 8-ft waves from northeast for maximum flood

Photo 15. Typical tracer movement for existing conditions resulting from 7-sec, 8-ft waves from northeast for slack water

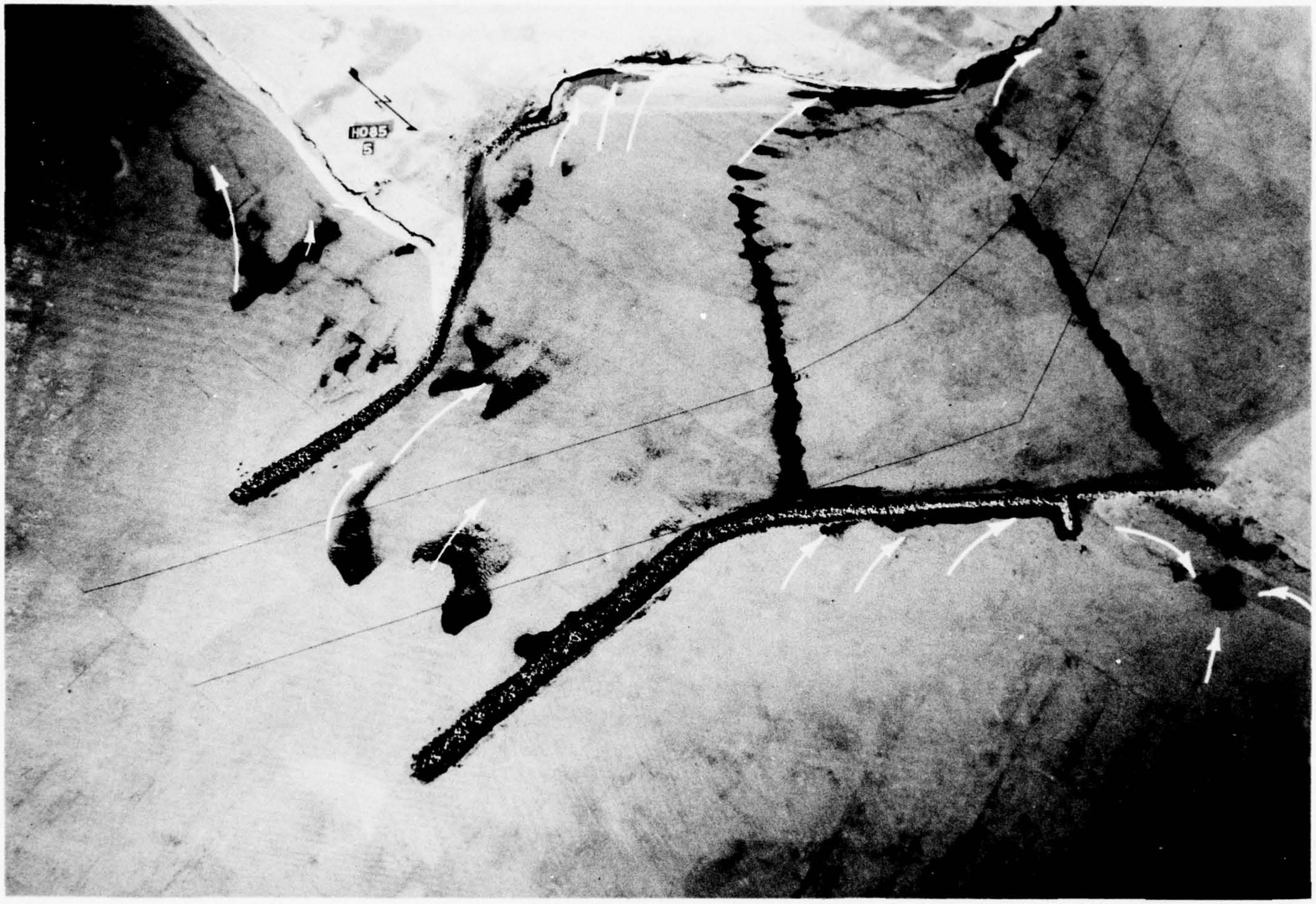

Photo 16. Typical tracer movement for existing conditions resulting from 11-sec, 9-ft waves from northeast for slack water

Photo 17. Typical tracer movement for existing conditions resulting from 7-sec, 8-ft waves from east for maximum ebb

Photo 18. Typical tracer movement for existing conditions resulting from 7-sec, 8-ft waves from east for maximum flood

Photo 19. Typical tracer movement for existing conditions resulting from 7-sec, 8-ft waves from east for slack water

Photo 20. Typical tracer movement for existing conditions resulting from 11-sec, 14-ft waves from east for slack water

Photo 21. Typical tracer movement for existing conditions resulting from 9-sec, 8-ft waves from southeast for maximm ebb

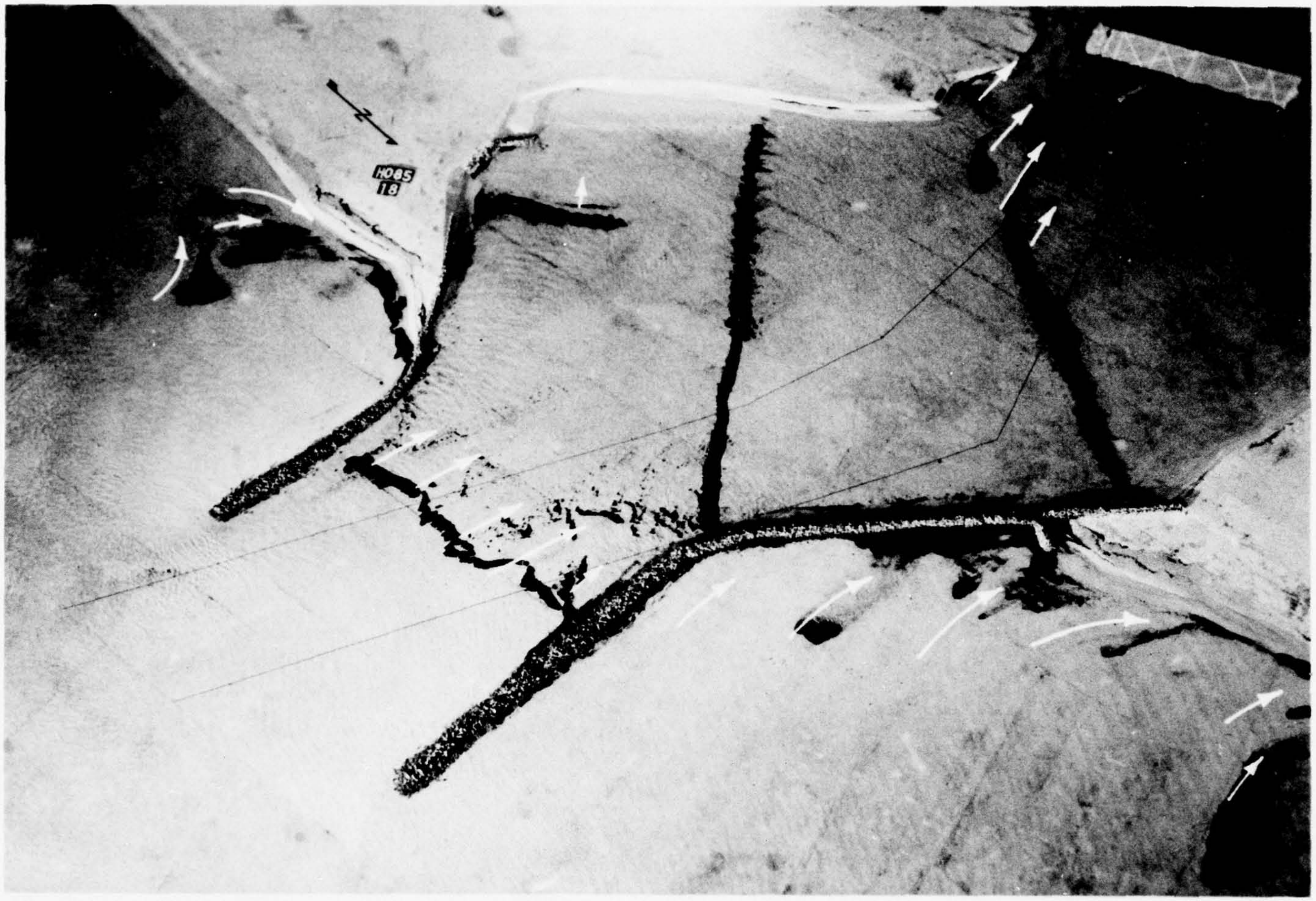

Photo 22. Typical tracer movement for existing conditions resulting from 9-sec, 8-ft waves from southeast for maximum flood

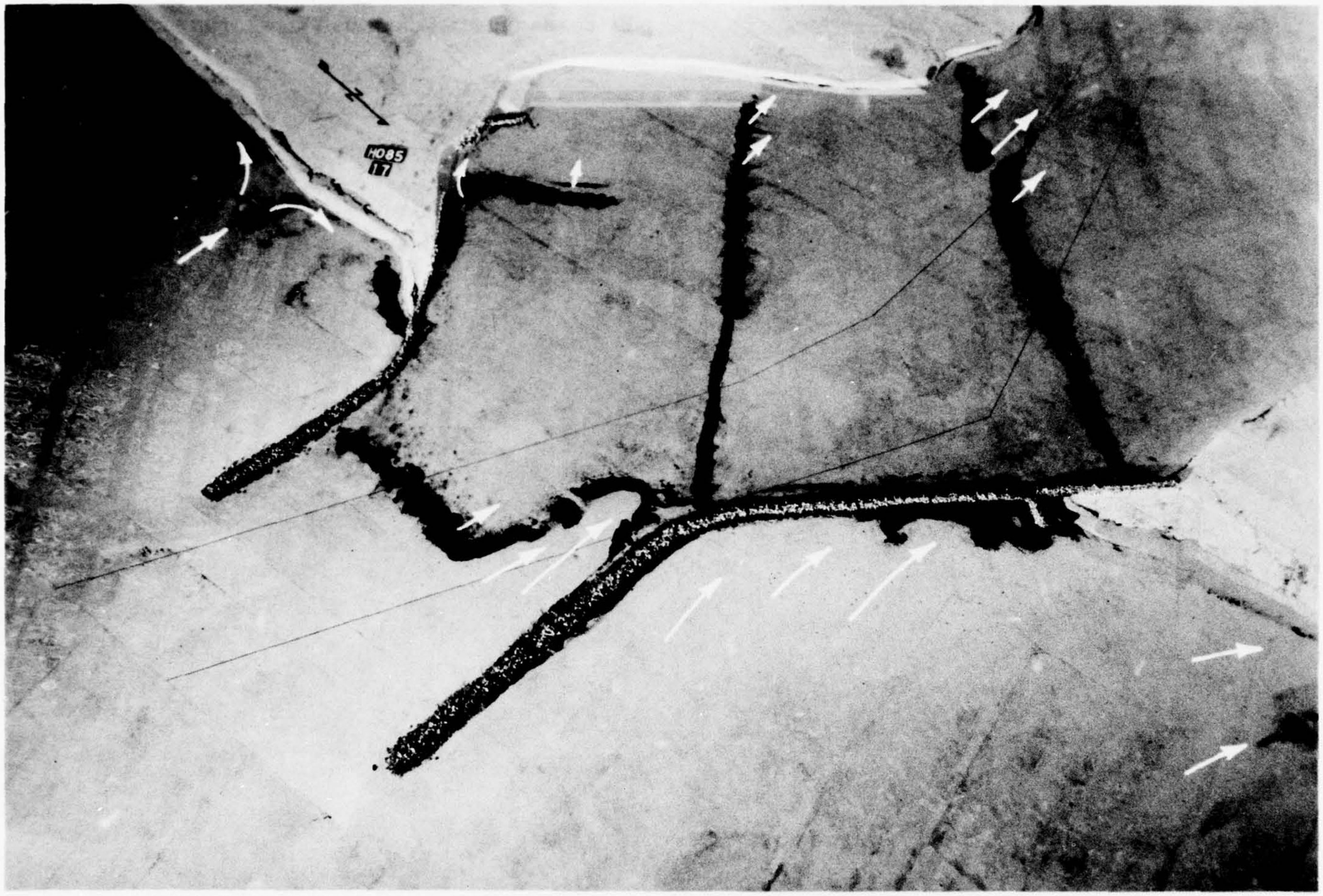

Photo 23. Typical tracer movement for existing conditions resulting from 9-sec, 8-ft waves from southeast for slack water

Photo 24. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 7-sec, 8-ft waves from northeast for maximum ebb

Photo 25. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 7-sec, 8-ft waves from northeast for maximum flood

Photo 26. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 7-sec, 8-ft waves from northeast for slack water

Photo 27. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 11-sec, 9-ft waves from northeast for slack water

Photo 28. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 7-sec, 8-ft waves from east for maximum ebb

Photo 29. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 7-sec, 8-ft waves from east for maximum flood

Photo 30. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 7-sec, 8-ft waves from east for slack water

Photo 31. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 11-sec, 14-ft waves from east for slack water

Photo 32. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 9-sec, 8-ft waves from southeast for maximum ebb

Photo 33. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 9-sec, 8-ft waves from southeast for maximum flood

Photo 34. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 2B; 9-sec, 8-ft waves from southeast for slack water

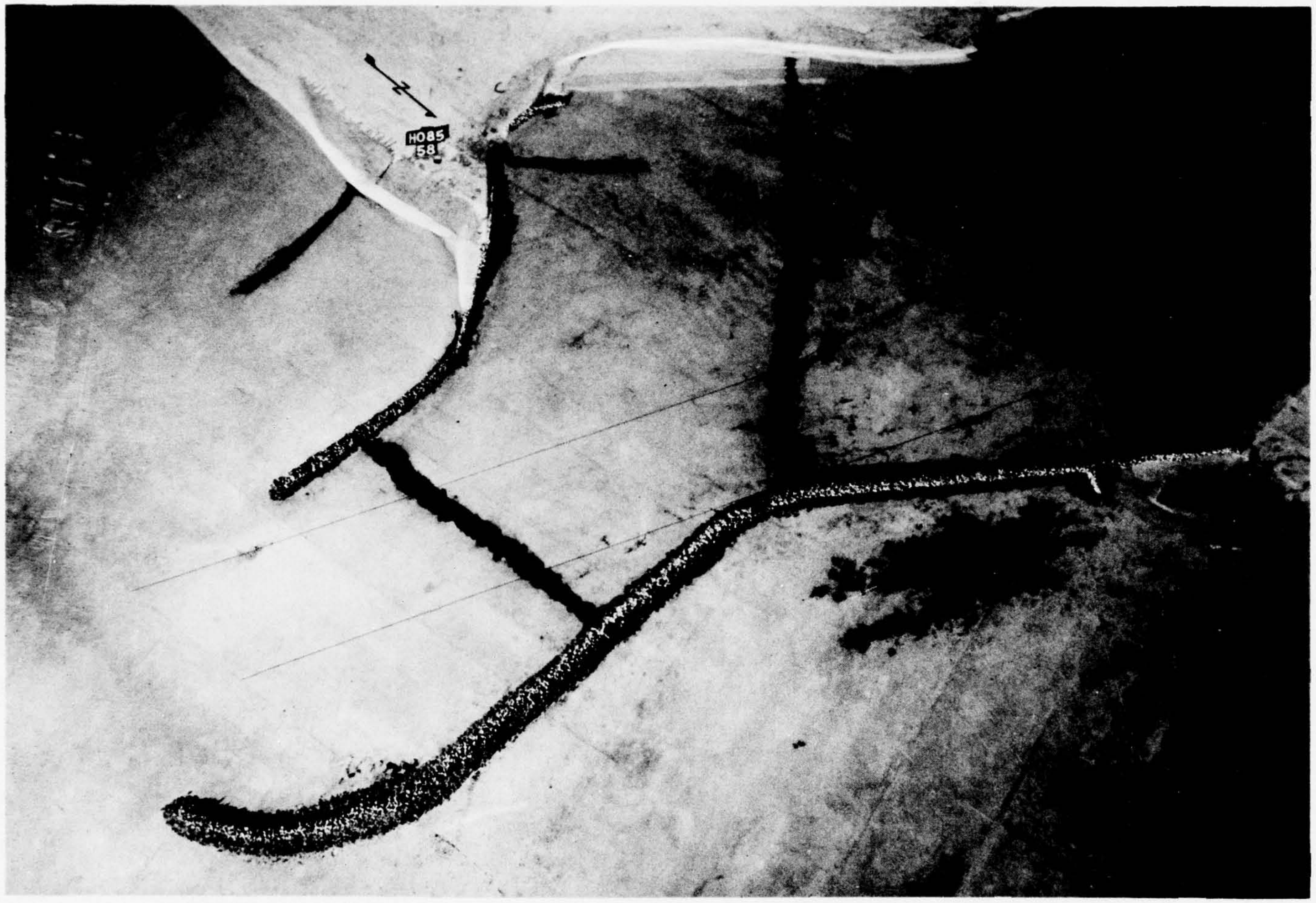

Photo 35. Tracer placement for plan 2B

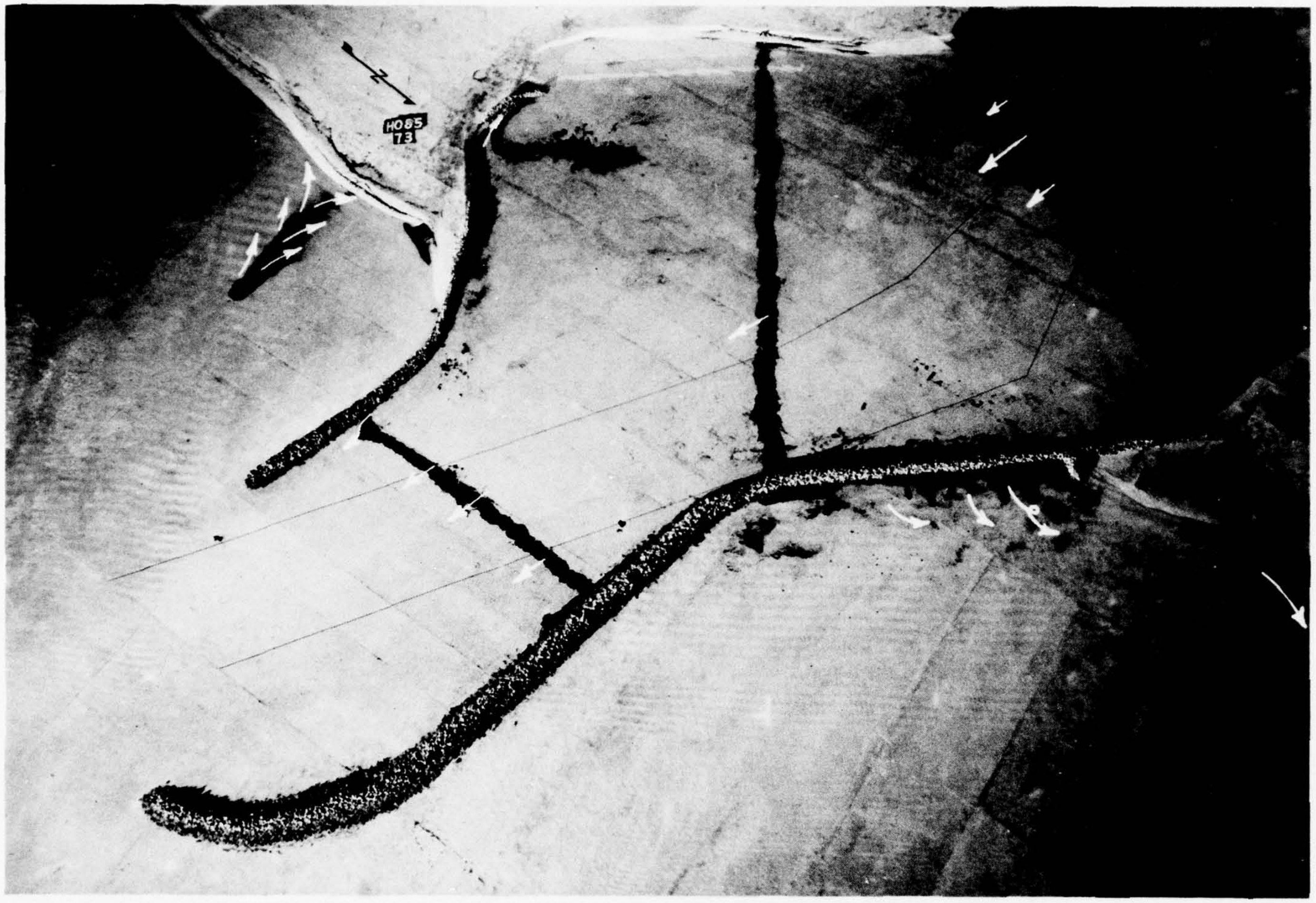

Photo 36. Typical tracer movement for plan 2B resulting from 7-sec, 8-ft waves from northeast for maximum ebb

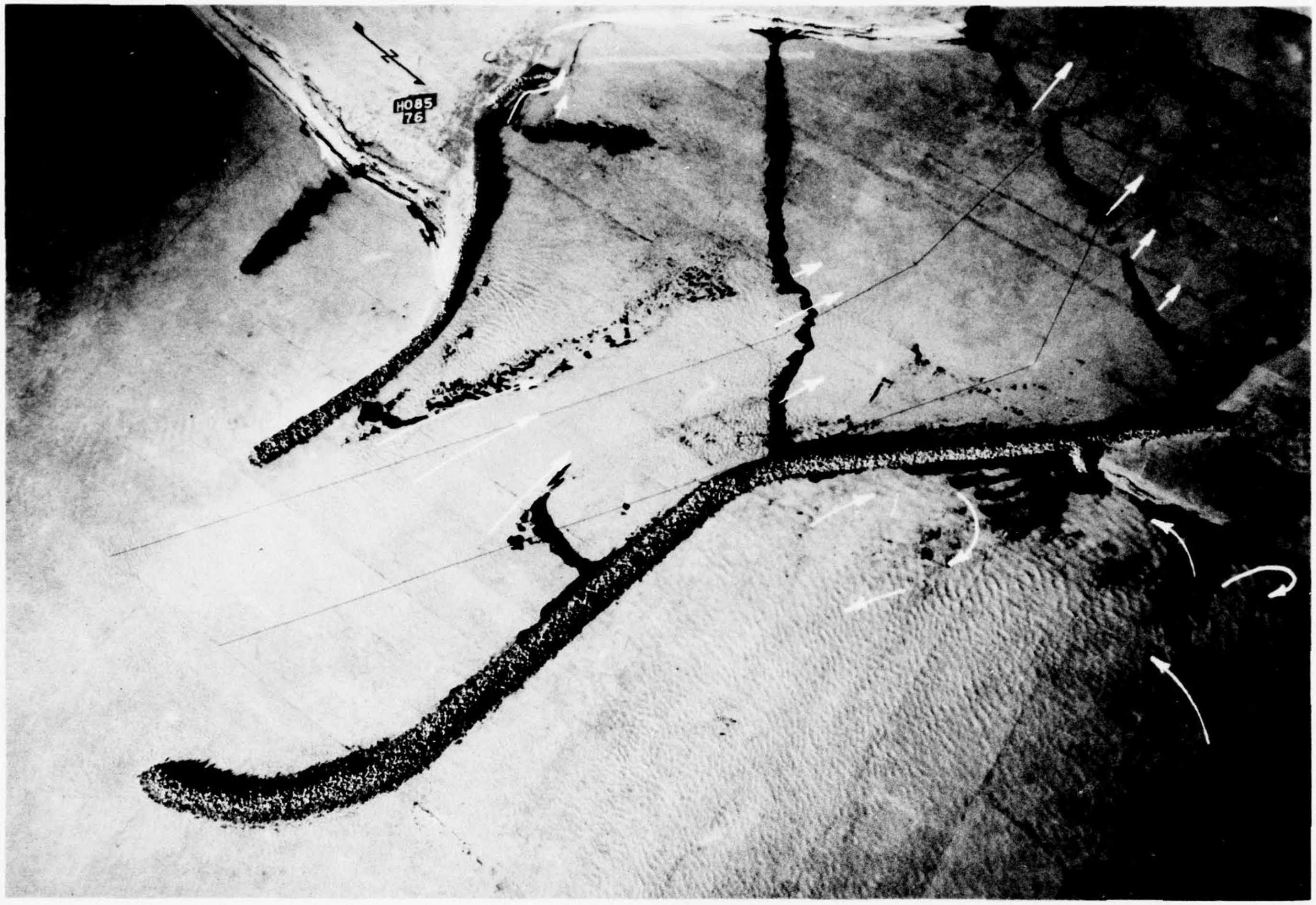

Photo 37. Typical tracer movement for plan 2B resulting from 7-sec, 8-ft waves from northeast for maximum flood

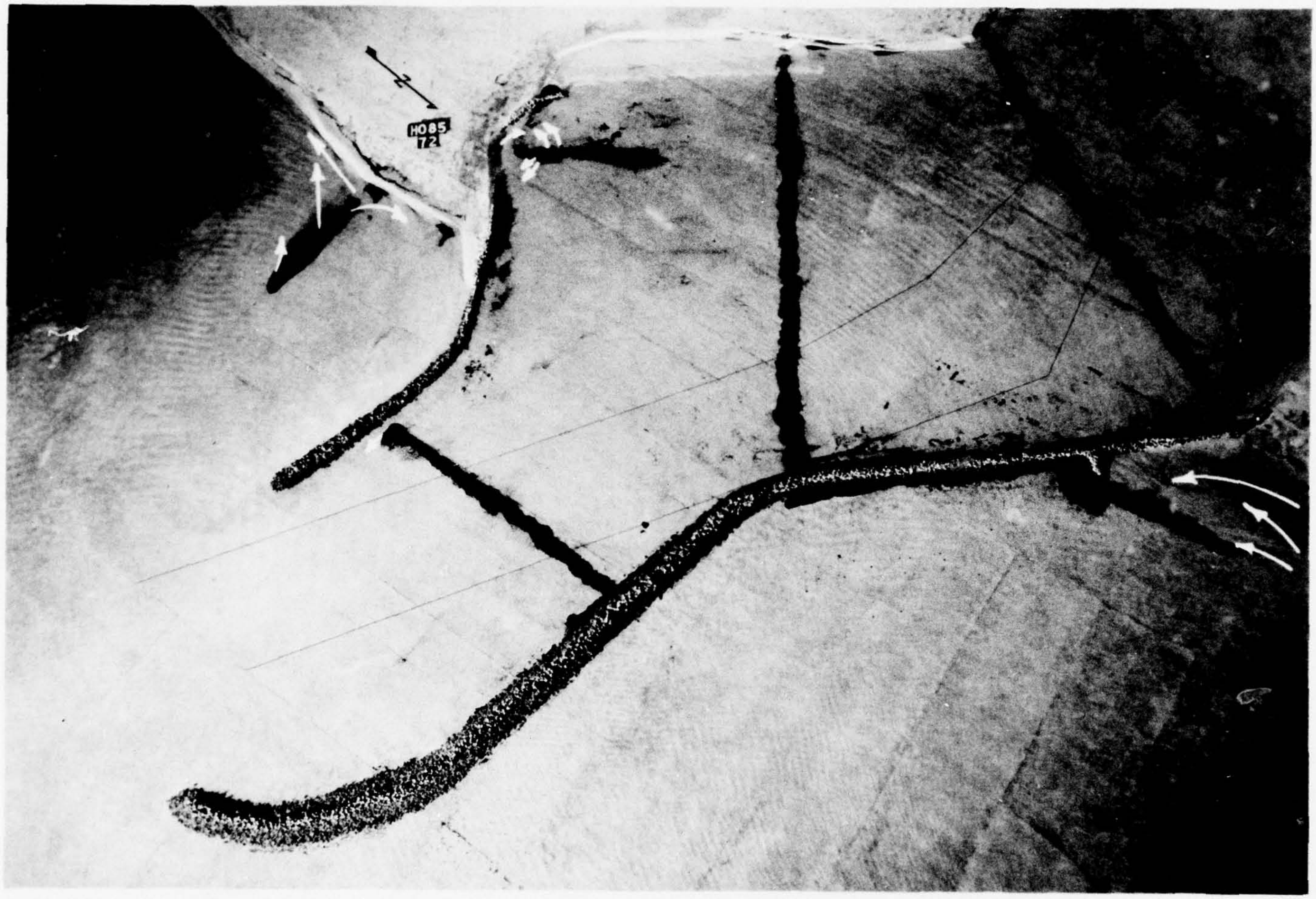

Photo 38. Typical tracer movement for plan 2B resulting from 7-sec, 8-ft waves from northeast for slack water

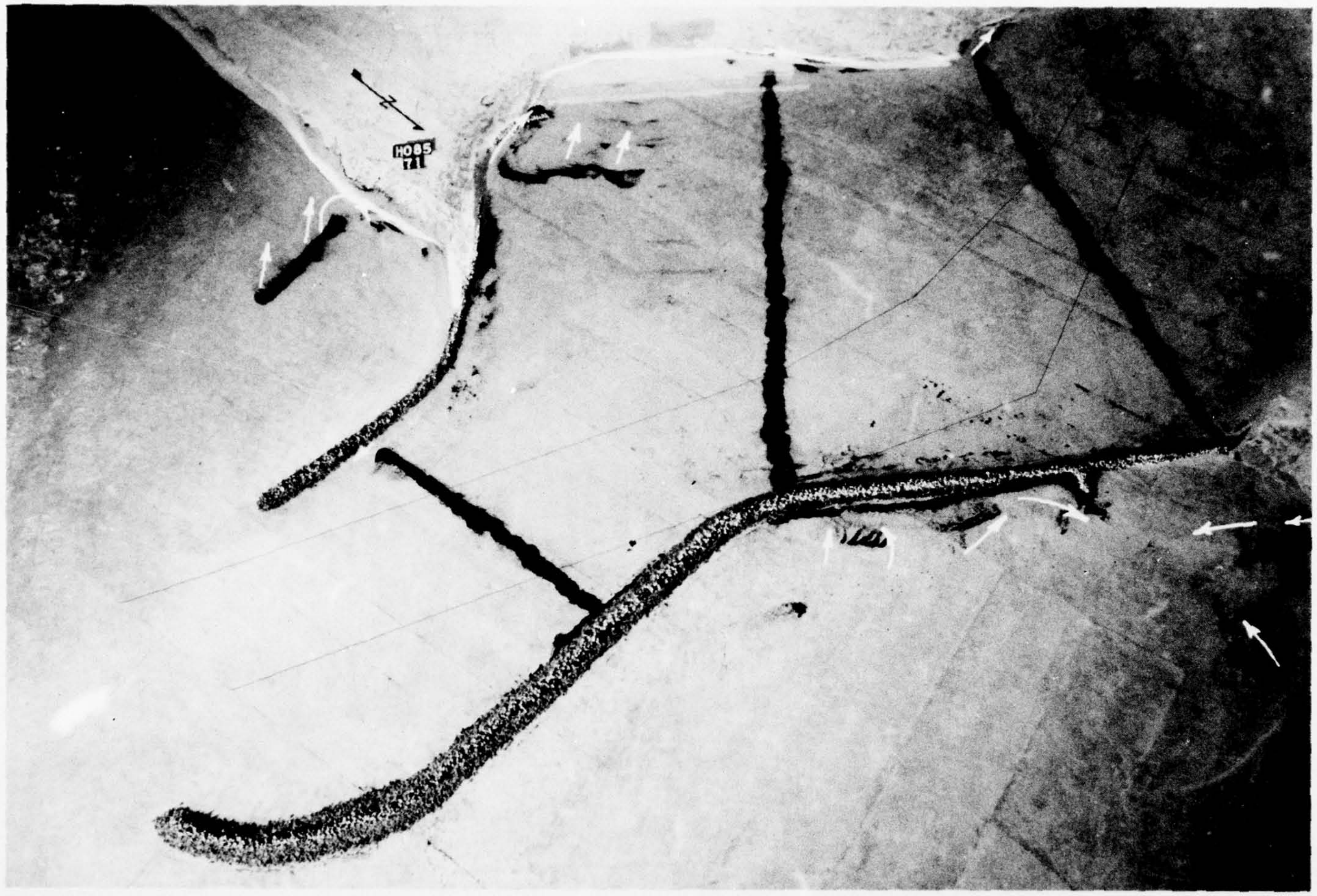

Photo 39. Typical tracer movement for plan 2B resulting from 11-sec, 9-ft waves from northeast for slack water

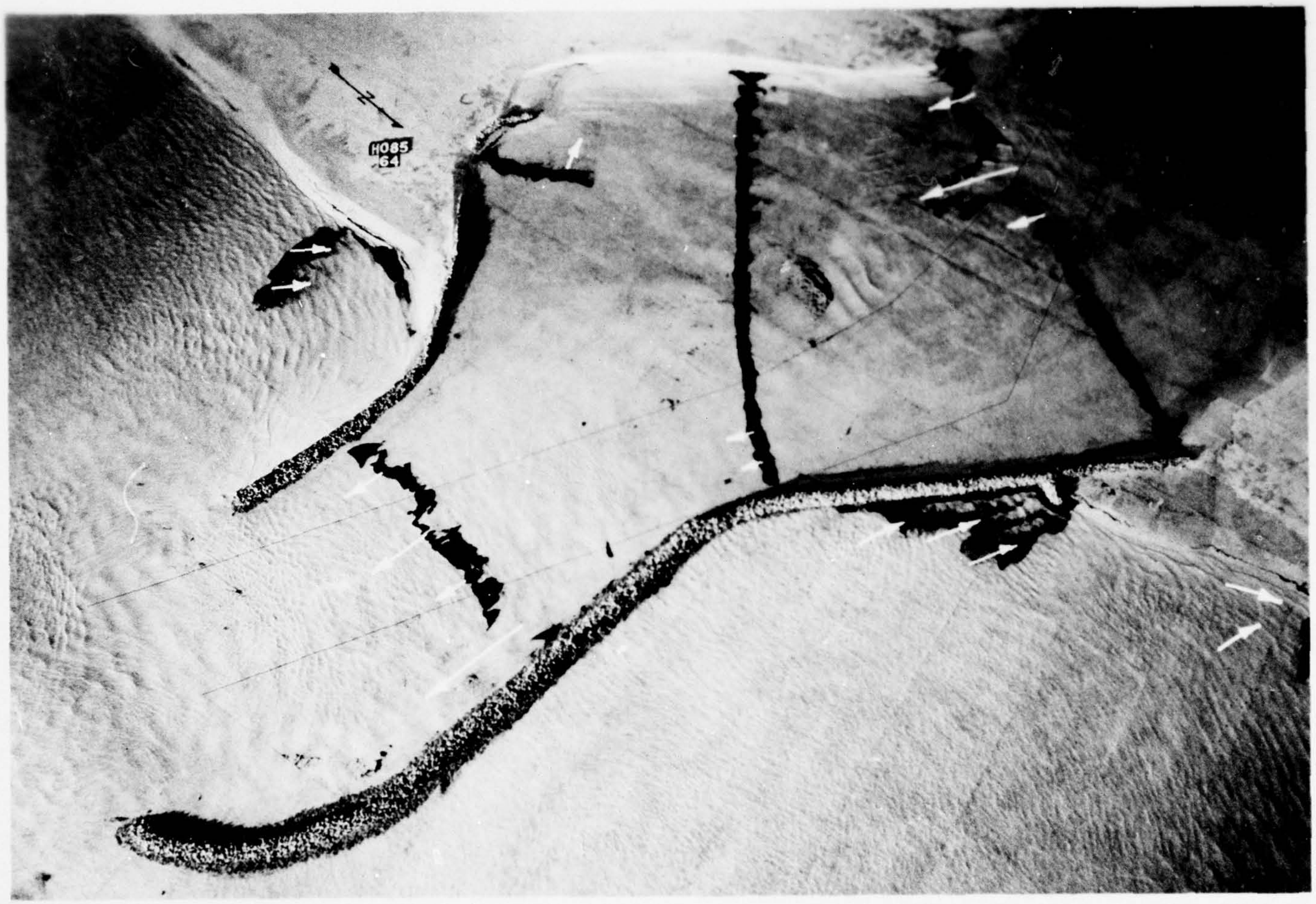

Photo 40. Typical tracer movement for plan 2B resulting from 7-sec, 8-ft waves from east for maximum ebb

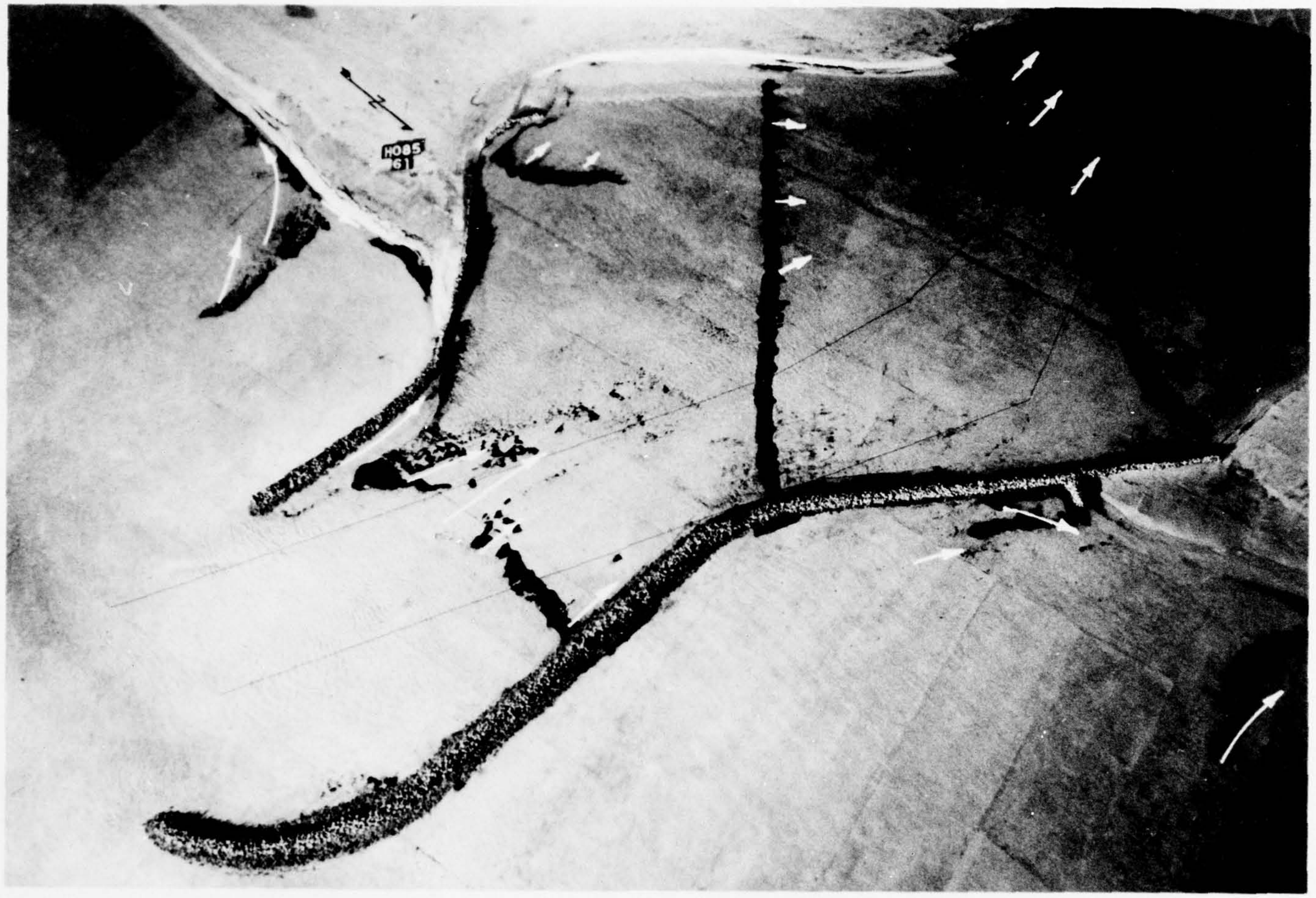

Photo 41. Typical tracer movement for plan 2B resulting from 7-sec, 8-ft waves from east for maximum flood

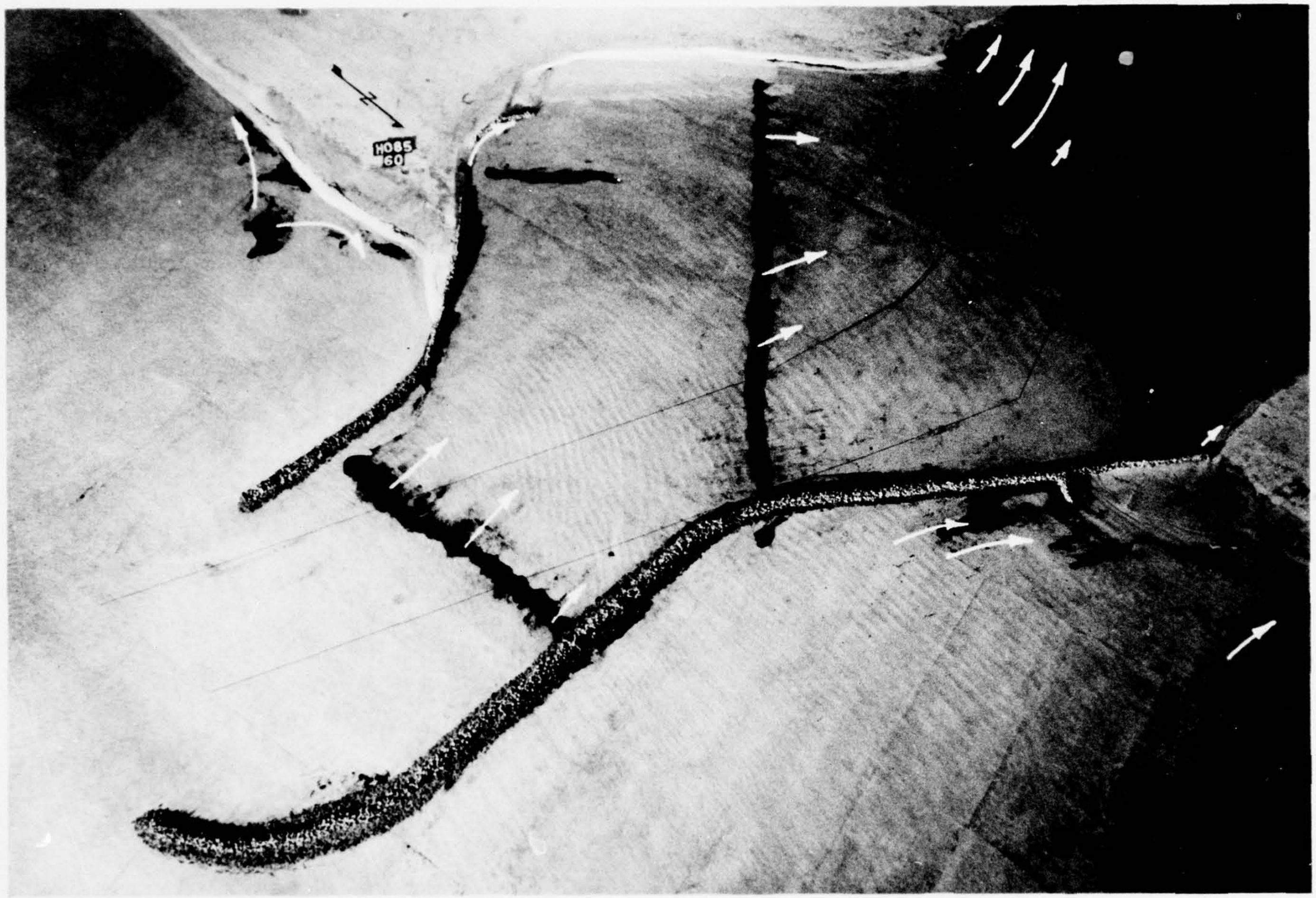

Photo 42. Typical tracer movement for plan 2B resulting from 7-sec, 8-ft waves from east for slack water

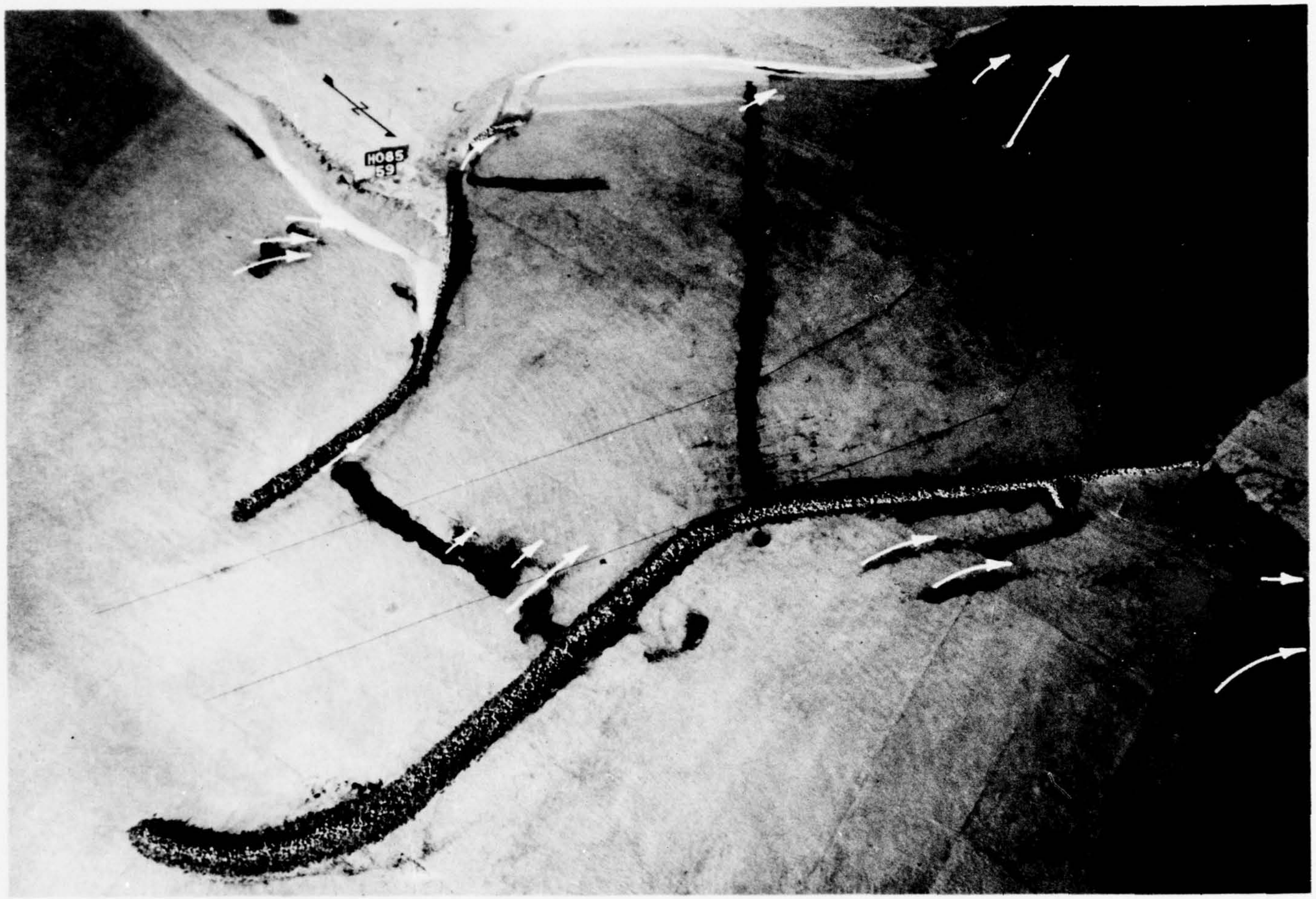

Photo 43. Typical tracer movment for plan 2B resulting from 11-sec, 14-ft waves from east for slack water

Photo 44. Typical tracer movement for plan 2B resulting from 9-sec, 8-ft waves from southeast for maximum ebb

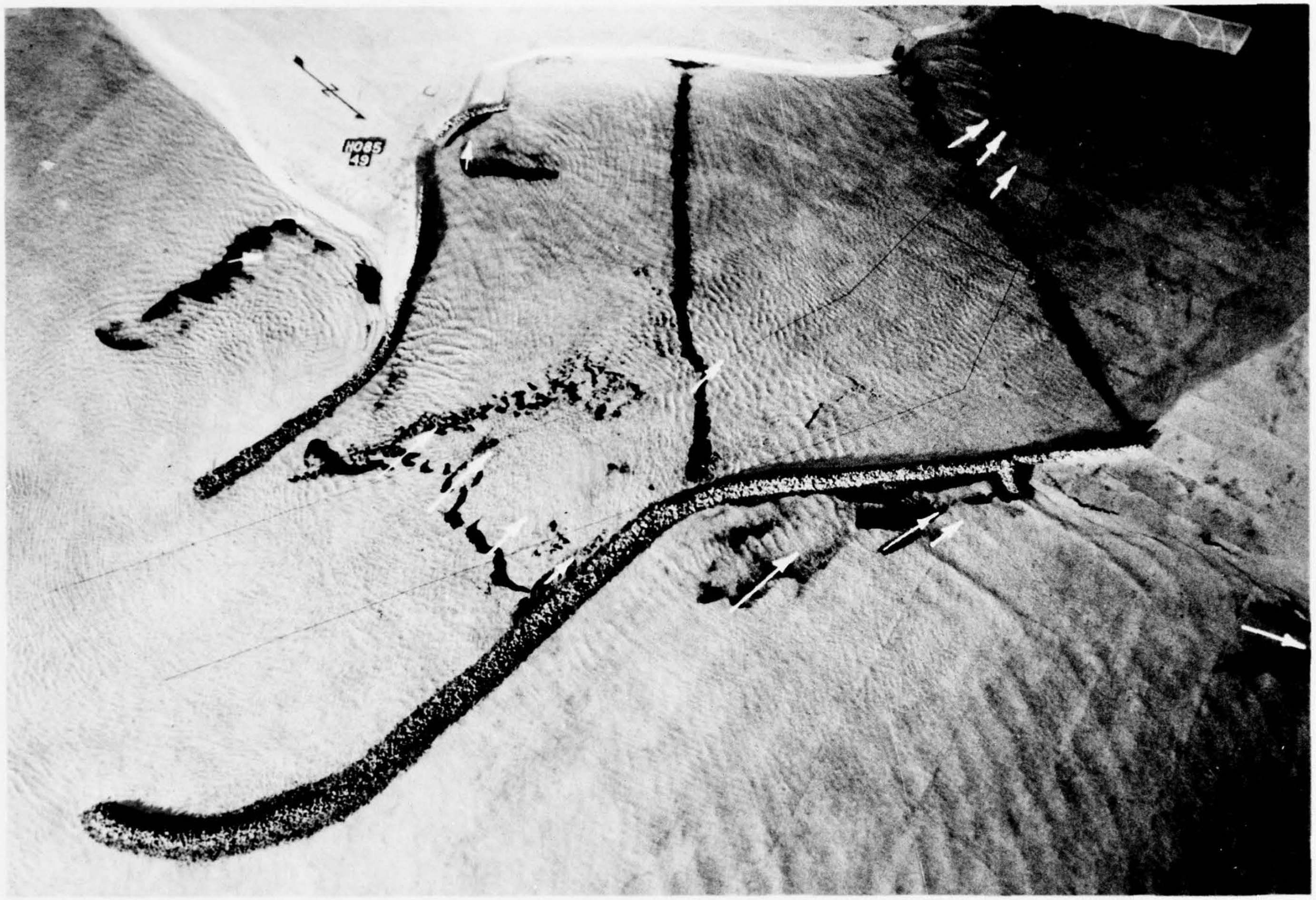

Photo 45. Typical tracer movement for plan 2B resulting from 9-sec, 8-ft waves from southeast for maximum flood

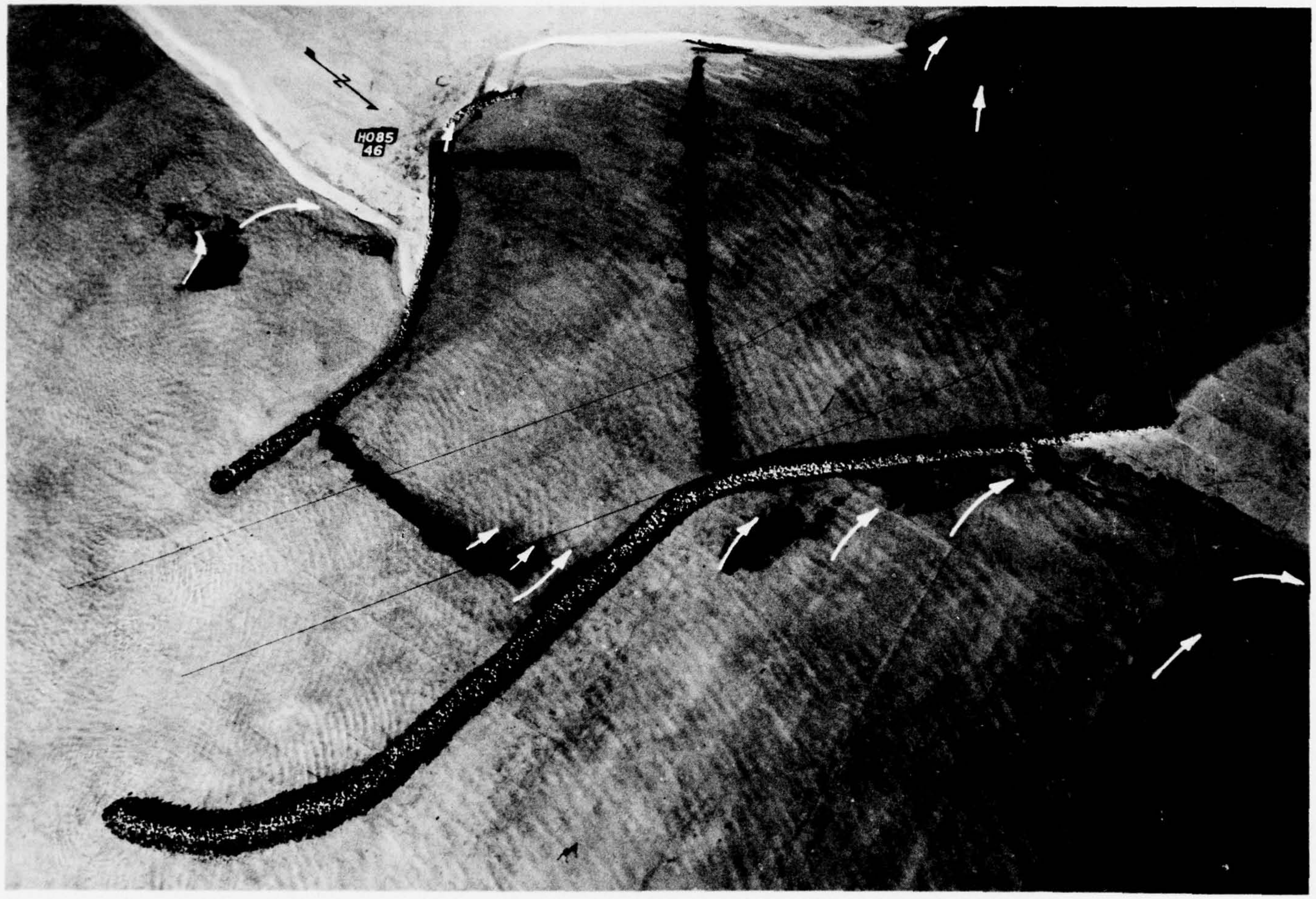

Photo 46. Typical tracer movement for plan 2B resulting from 9-sec, 8-ft waves from southeast for slack water

Photo 47. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 3; 7-sec, 8-ft waves from northeast for maximum ebb

Photo 48. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 3; 7-sec, 8-ft waves from northeast for maximum flood

Photo 49. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 3; 7-sec, 8-ft waves from northeast for slack water

Photo 50. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 3; 11-sec, 9-ft waves from northeast for slack water

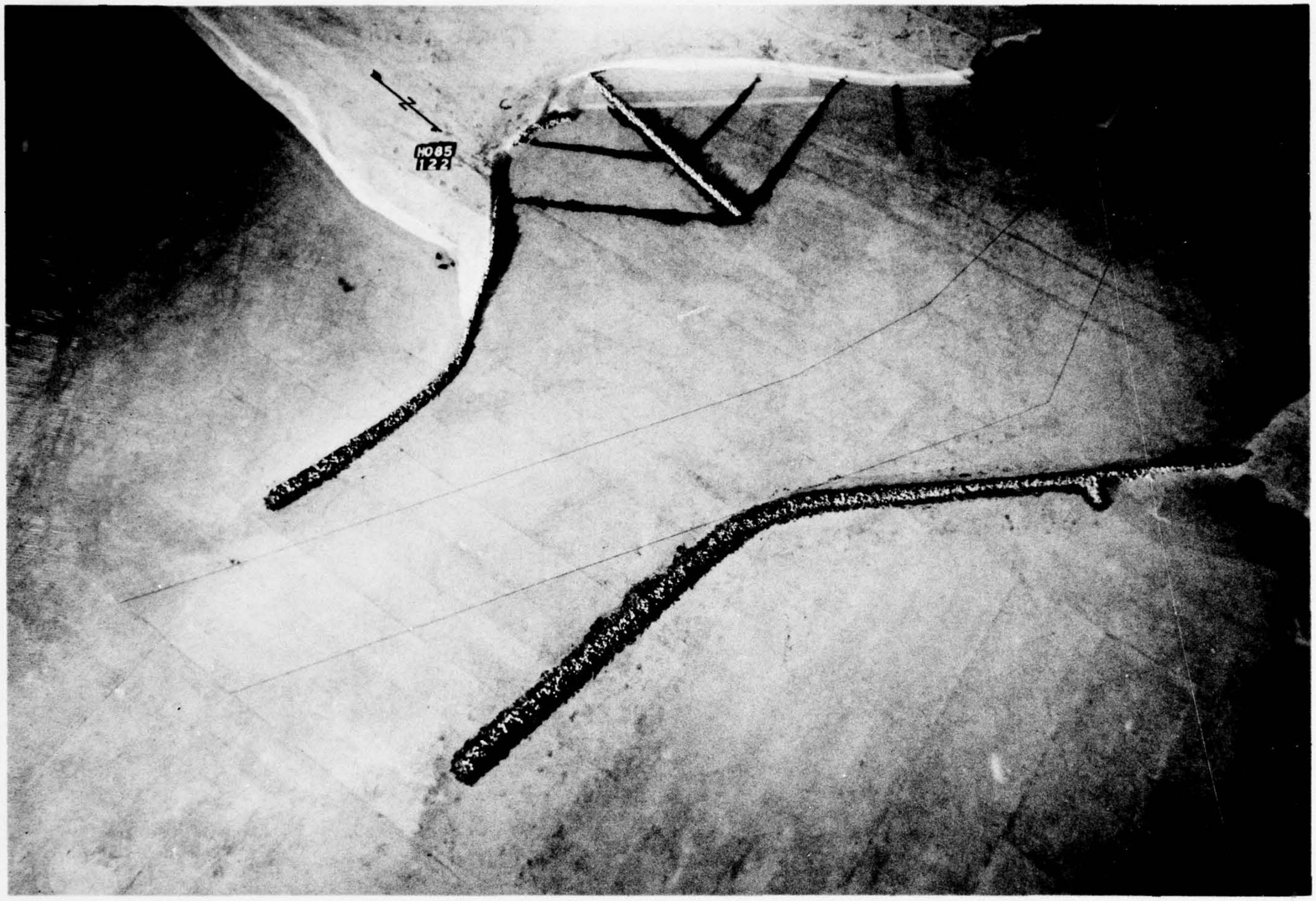

Photo 51. Tracer placement for plan 3

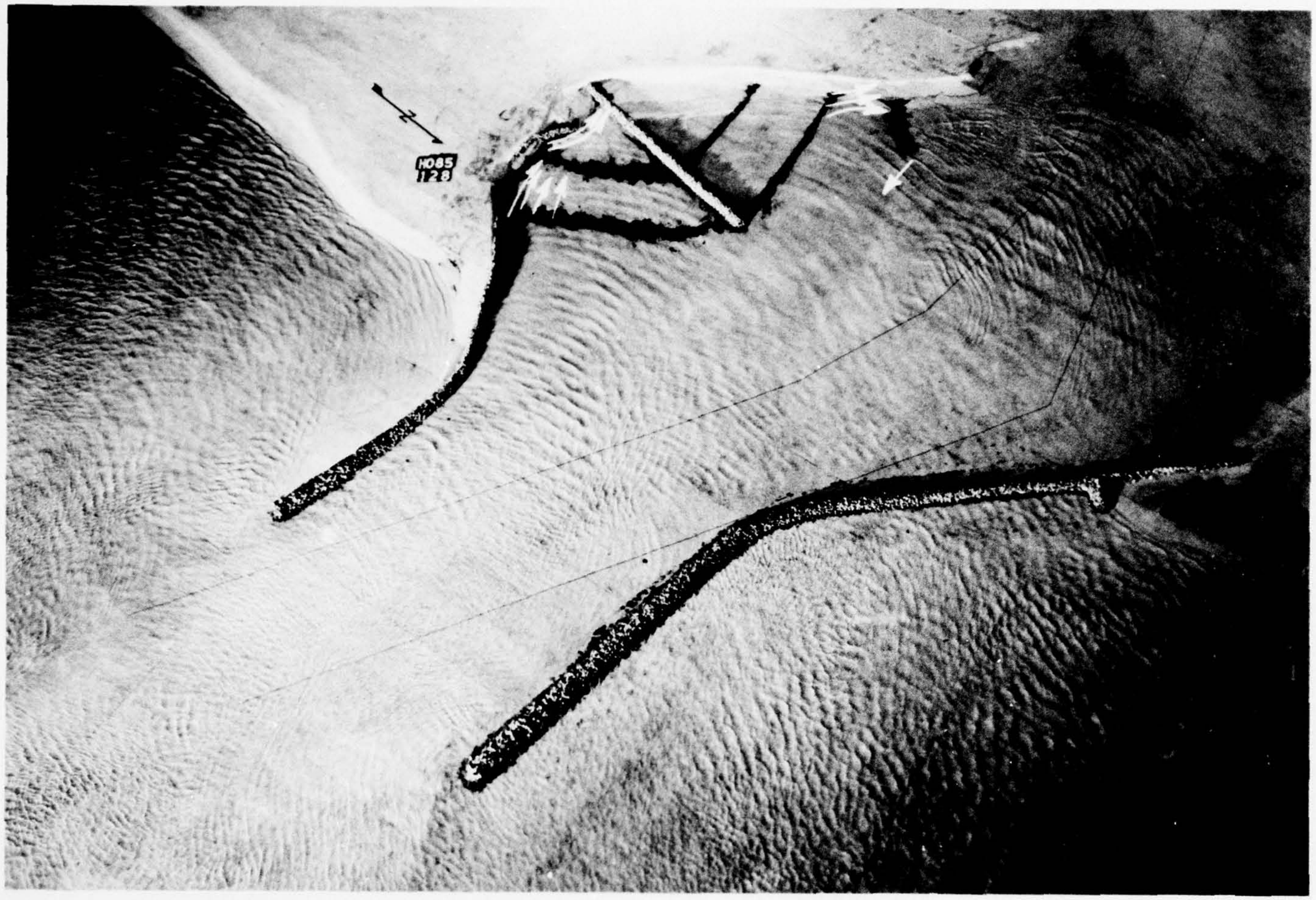

Photo 52. Typical tracer movement for plan 3 resulting from 7-sec, 8-ft waves from northeast for maximum ebb

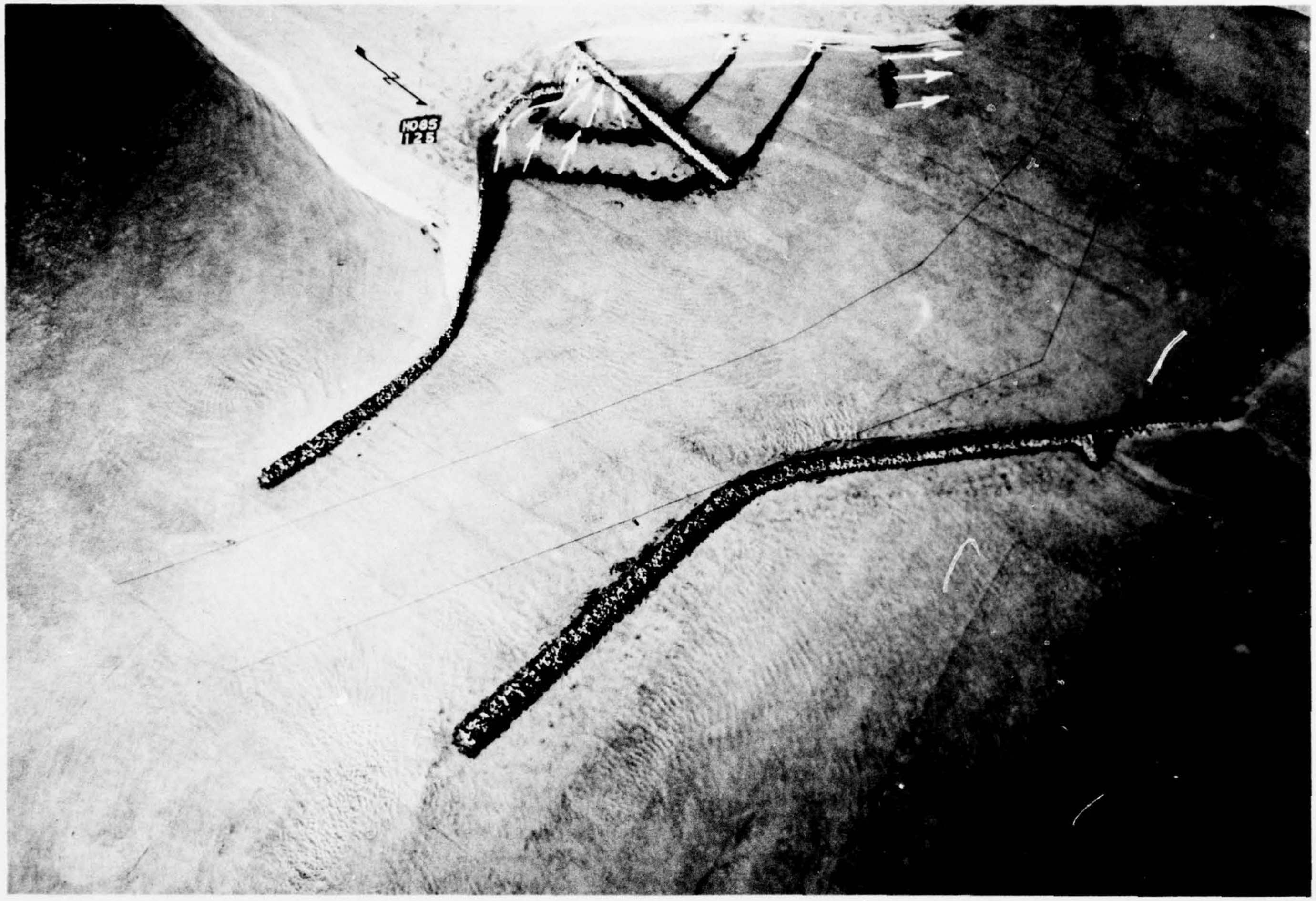

Photo 53. Typical tracer movement for plan 3 resulting from 7-sec, 8-ft waves from northeast for maximum flood

AD-A066 361 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 8/3
NEWBURYPORT HARBOR, MASSACHUSETTS; REPORT 1. DESIGN FOR WAVE PR--ETC(U)
FEB 79 C R CURREN, C E CHATHAM
UNCLASSIFIED WES-TR-HL-79-1 NL

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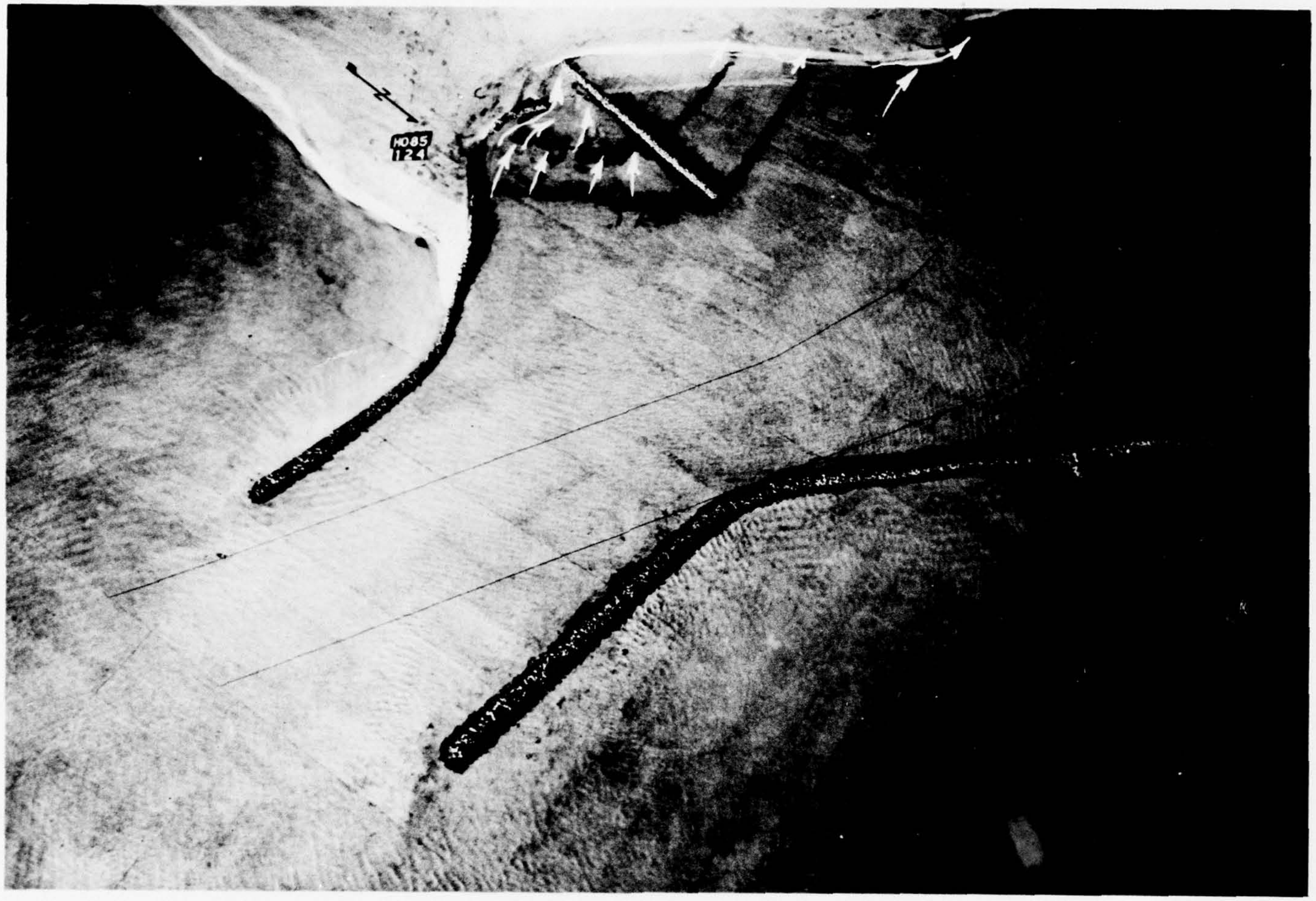


Photo 54. Typical tracer mvement for plan 3 resulting from 7-sec, 8-ft waves from northeast for slack water

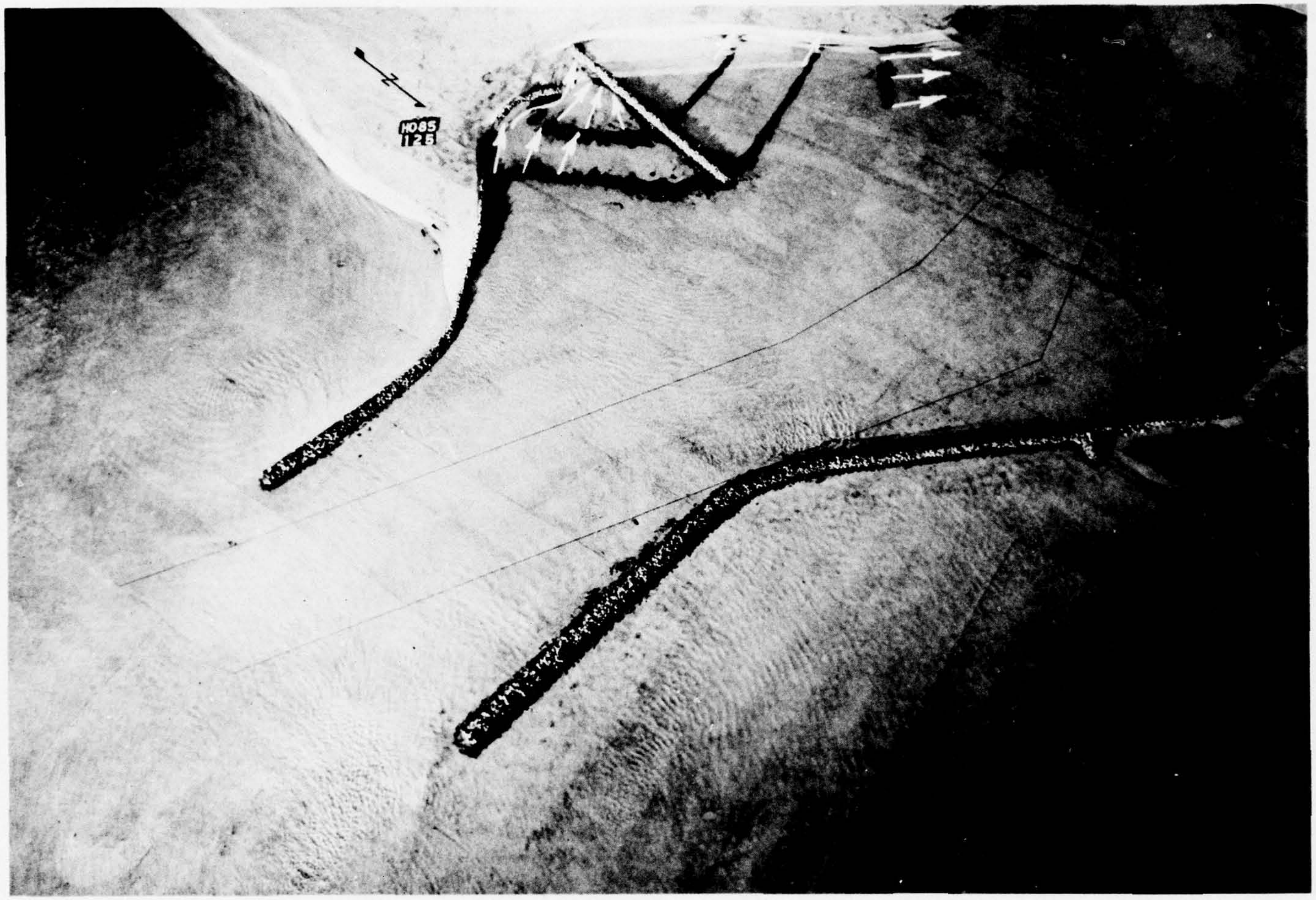


Photo 53. Typical tracer movement for plan 3 resulting from 7-sec, 8-ft waves from northeast for maximum flood

Photo 55. Typical tracer movement for plan 3 resulting from 11-sec, 9-ft waves from northeast for slack water

Photo 56. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 3A; 7-sec, 8-ft waves from northeast for maximum ebb

Photo 66. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 4; 7-sec, 8-ft waves from northeast for slack water

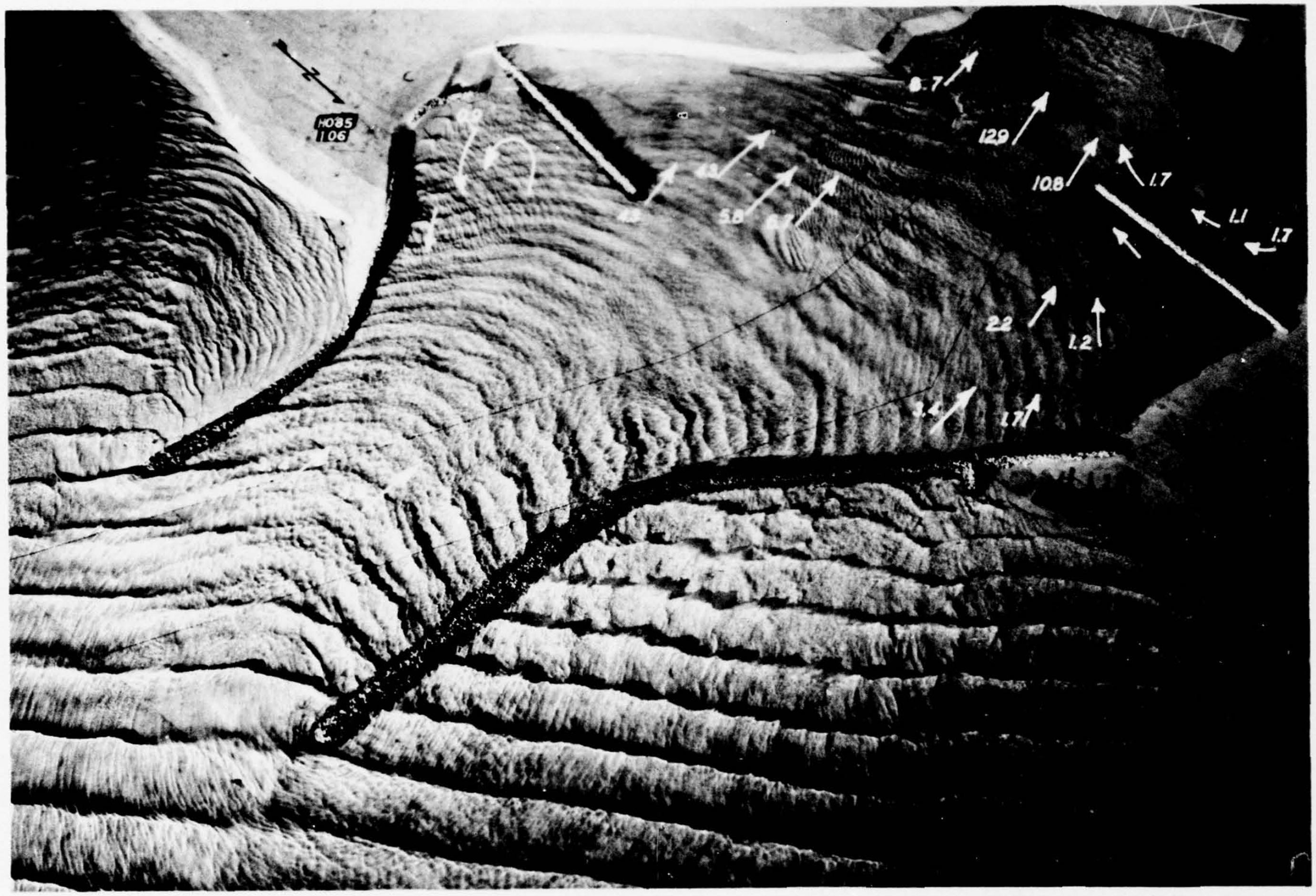


Photo 65. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 4; 7-sec, 8-ft waves from northeast for maximum flood

Photo 64. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 4; 7-sec, 8-ft waves from northeast for maximum ebb

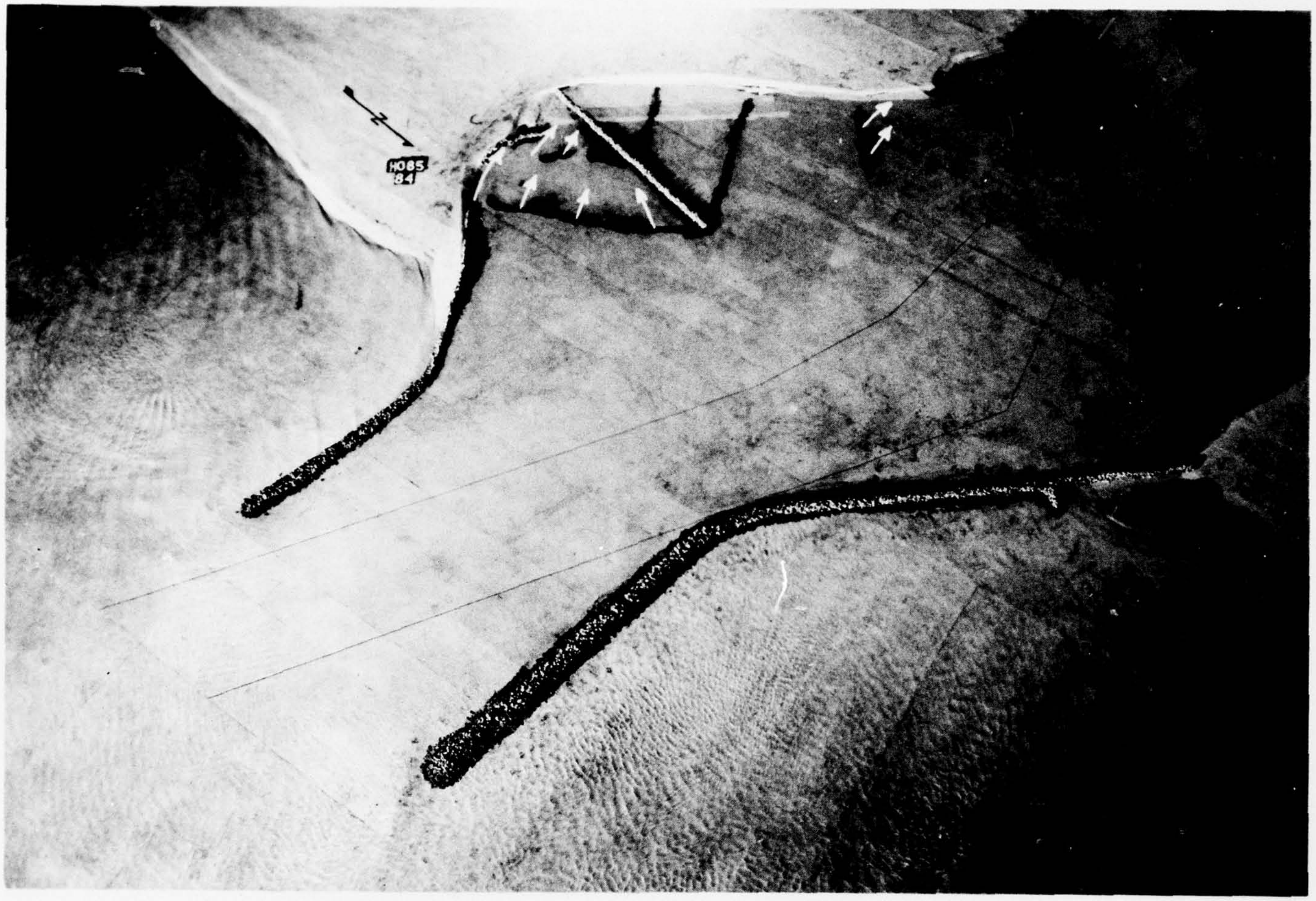


Photo 63. Typical tracer movement for plan 3A resulting from 11-sec, 9-ft waves from northeast for slack water

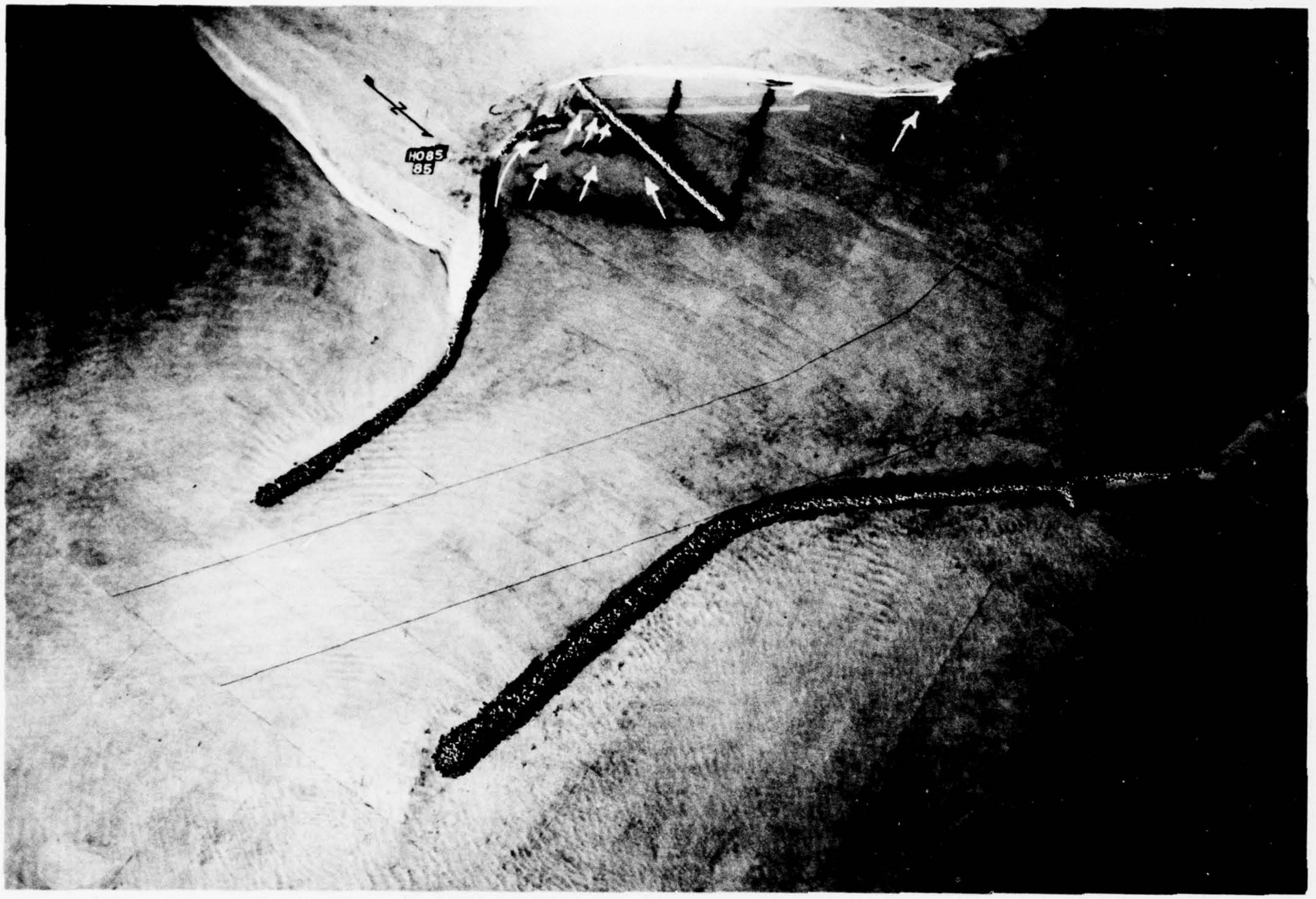


Photo 62. Typical tracer movement for plan 3A resulting from 7-sec, 8-ft waves from northeast for slack water

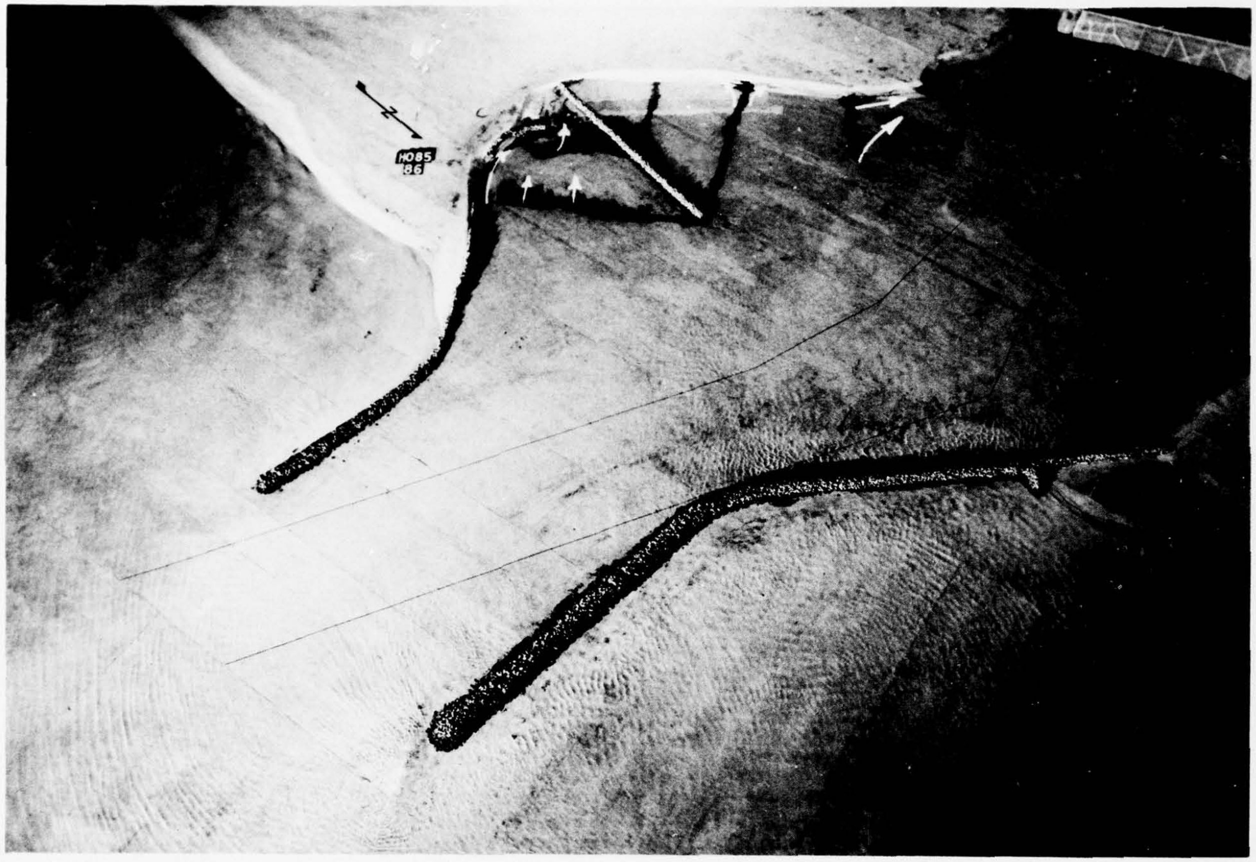


Photo 61. Typical tracer movement for plan 3A resulting from 7-sec, 8-ft waves from northeast for maximum flood

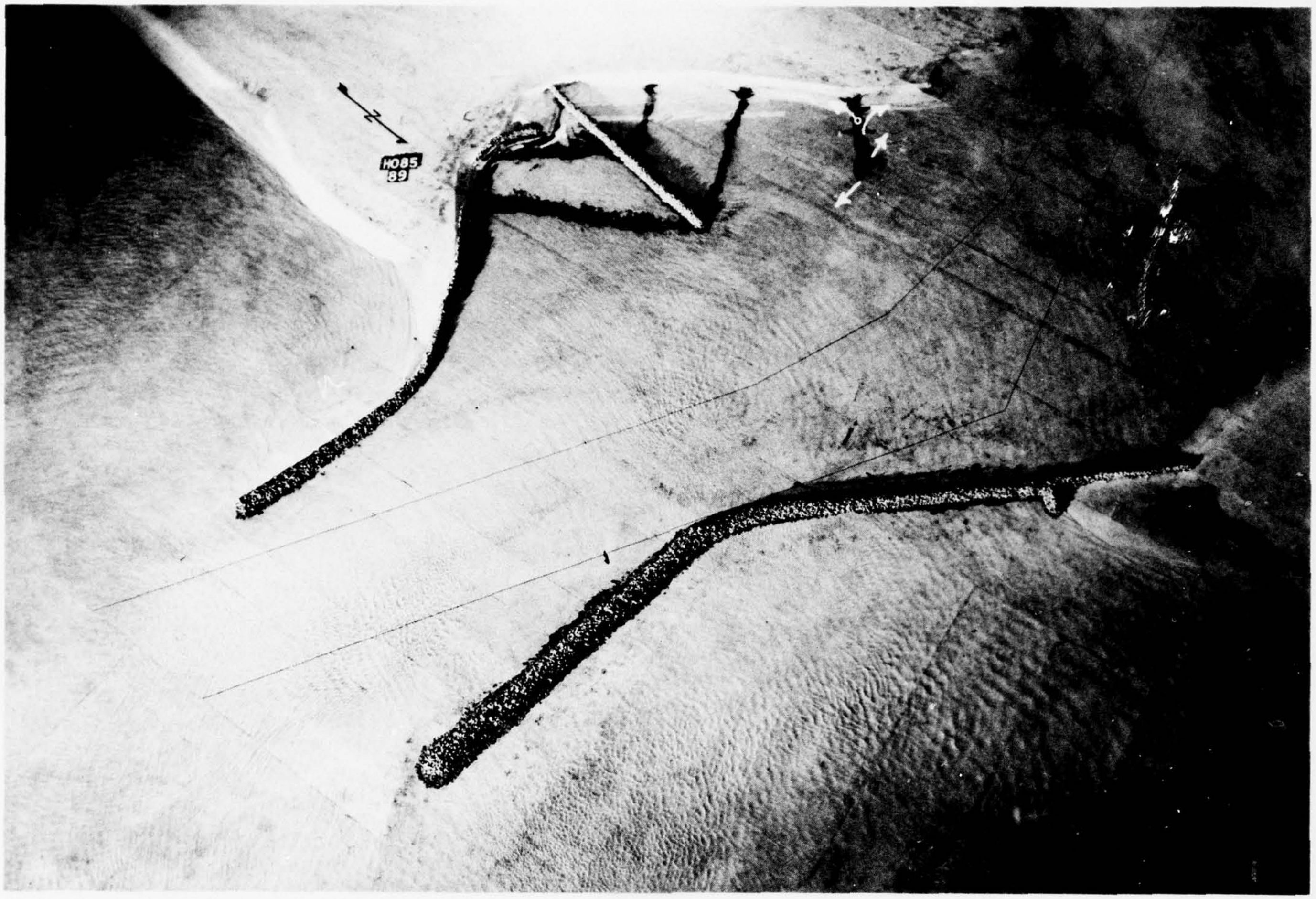


Photo 60. Typical tracer movement for plan 3A resulting from 7-sec, 8-ft waves from northeast for maximum ebb

Photo 59. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 3A; 11-sec, 9-ft waves from northeast for slack water

Photo 58. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 3A; 7-sec, 8-ft waves from northeast for slack water

Photo 57. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 3A; 7-sec, 8-ft waves from northeast for maximum flood

Photo 74. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 4A; 7-sec, 8-ft waves from northeast for maximum flood

Photo 73. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 4A; 7-sec, 8-ft waves from northeast for maximum ebb

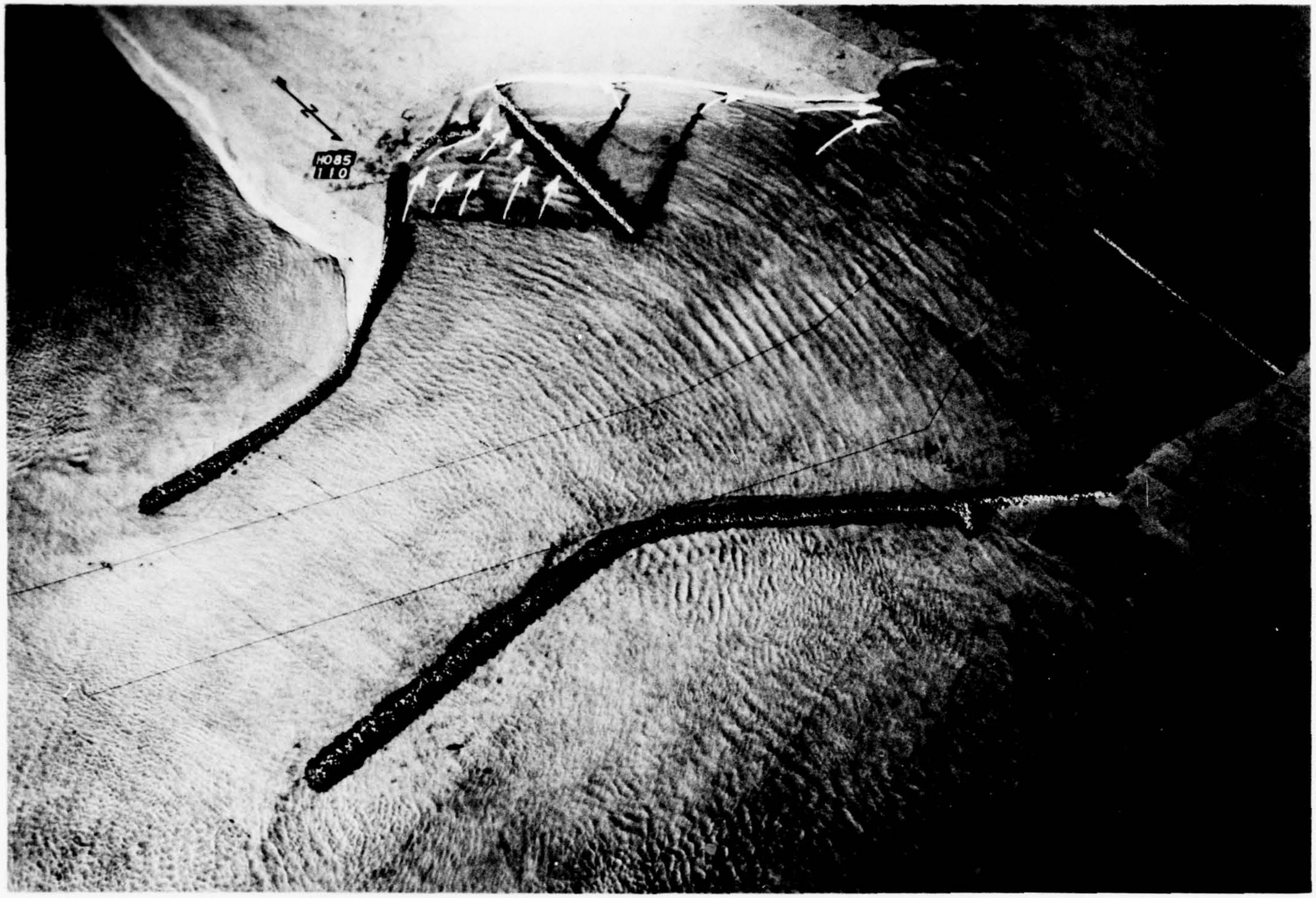


Photo 72. Typical tracer movement for plan 4 resulting from 11-sec, 9-ft waves from northeast for slack water

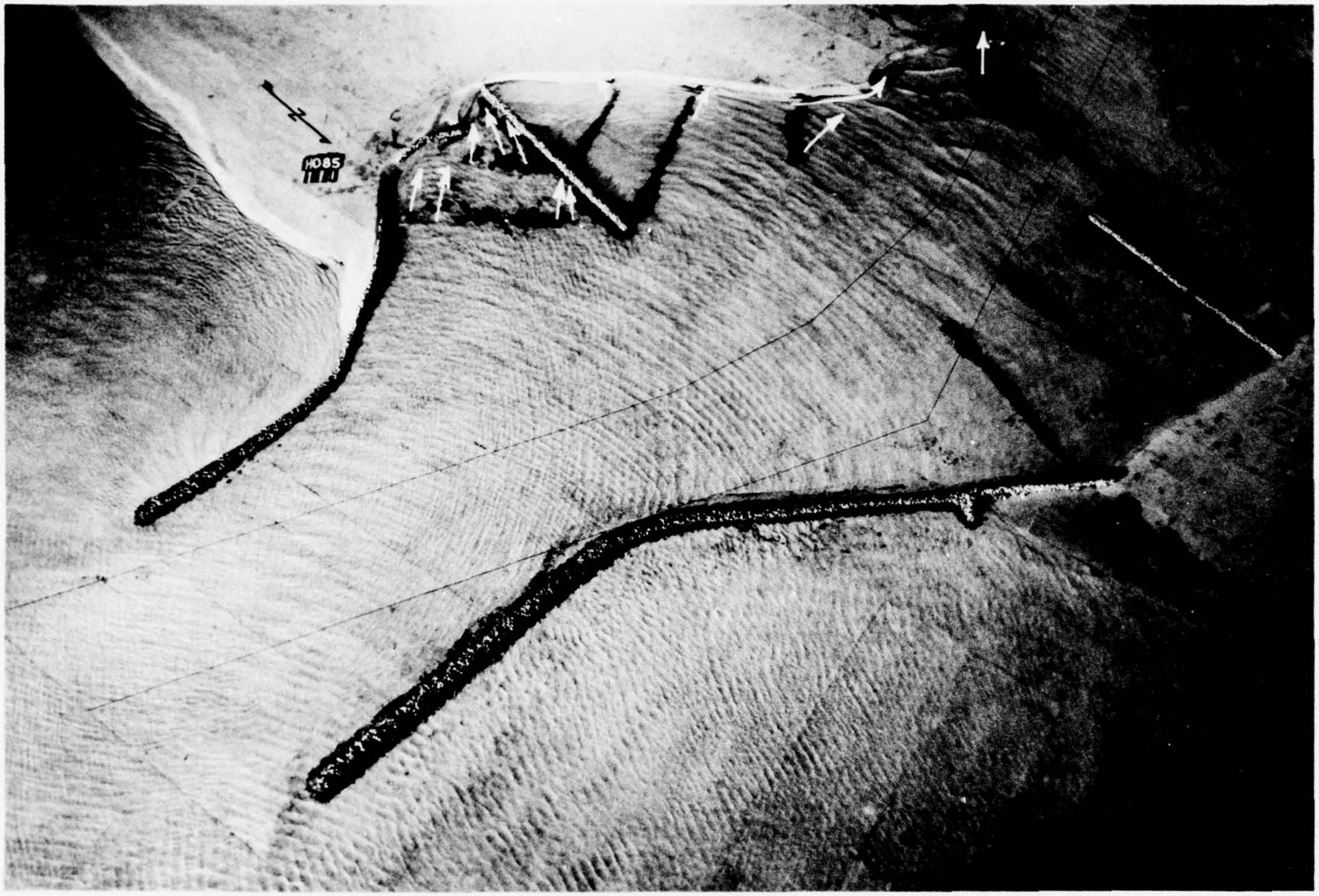


Photo 71. Typical tracer movement for plan 4 resulting from 7-sec, 8-ft waves from northeast for slack water

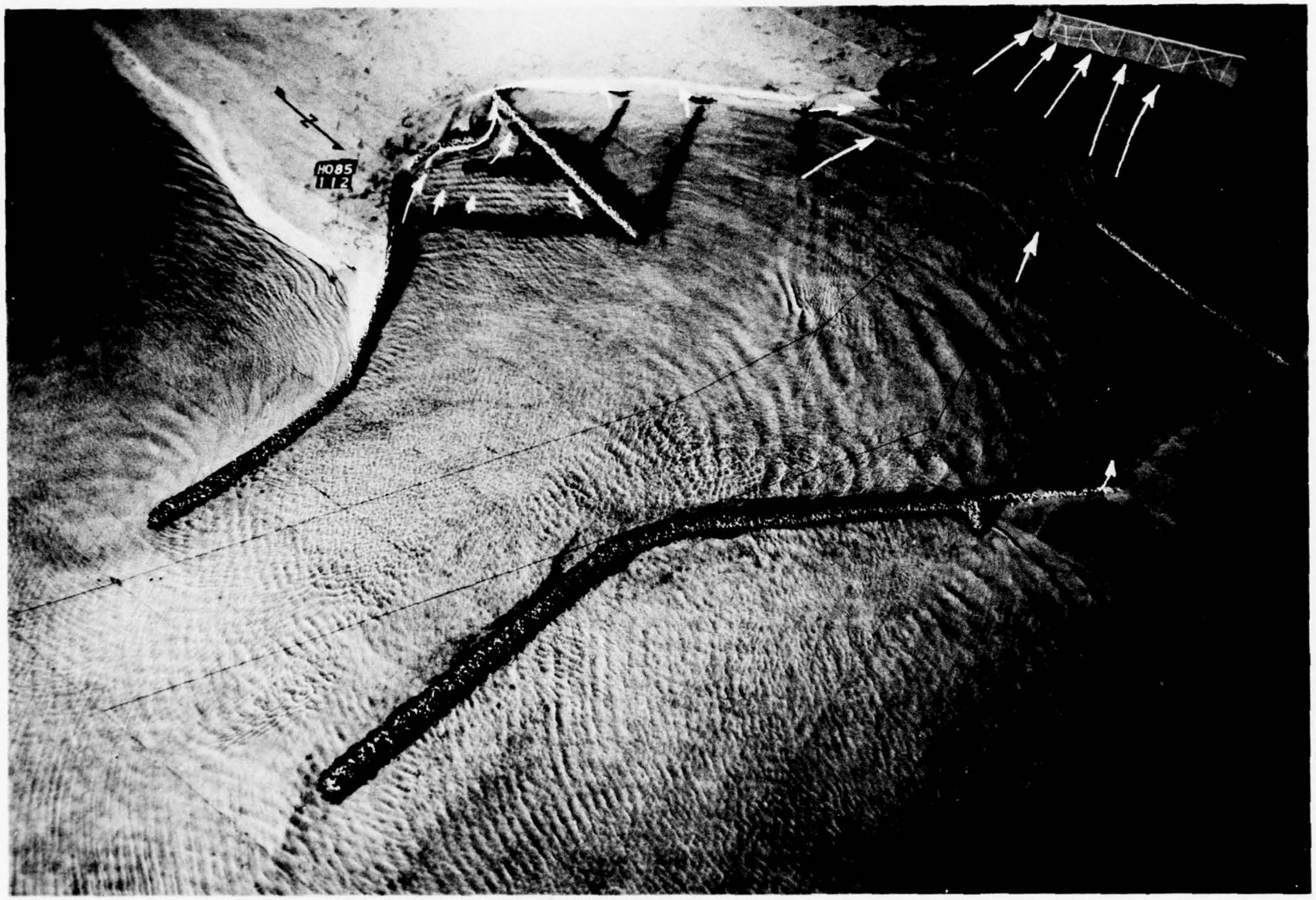


Photo 70. Typical tracer movement for plan 4 resulting from 7-sec, 8-ft waves from northeast for maximum flood

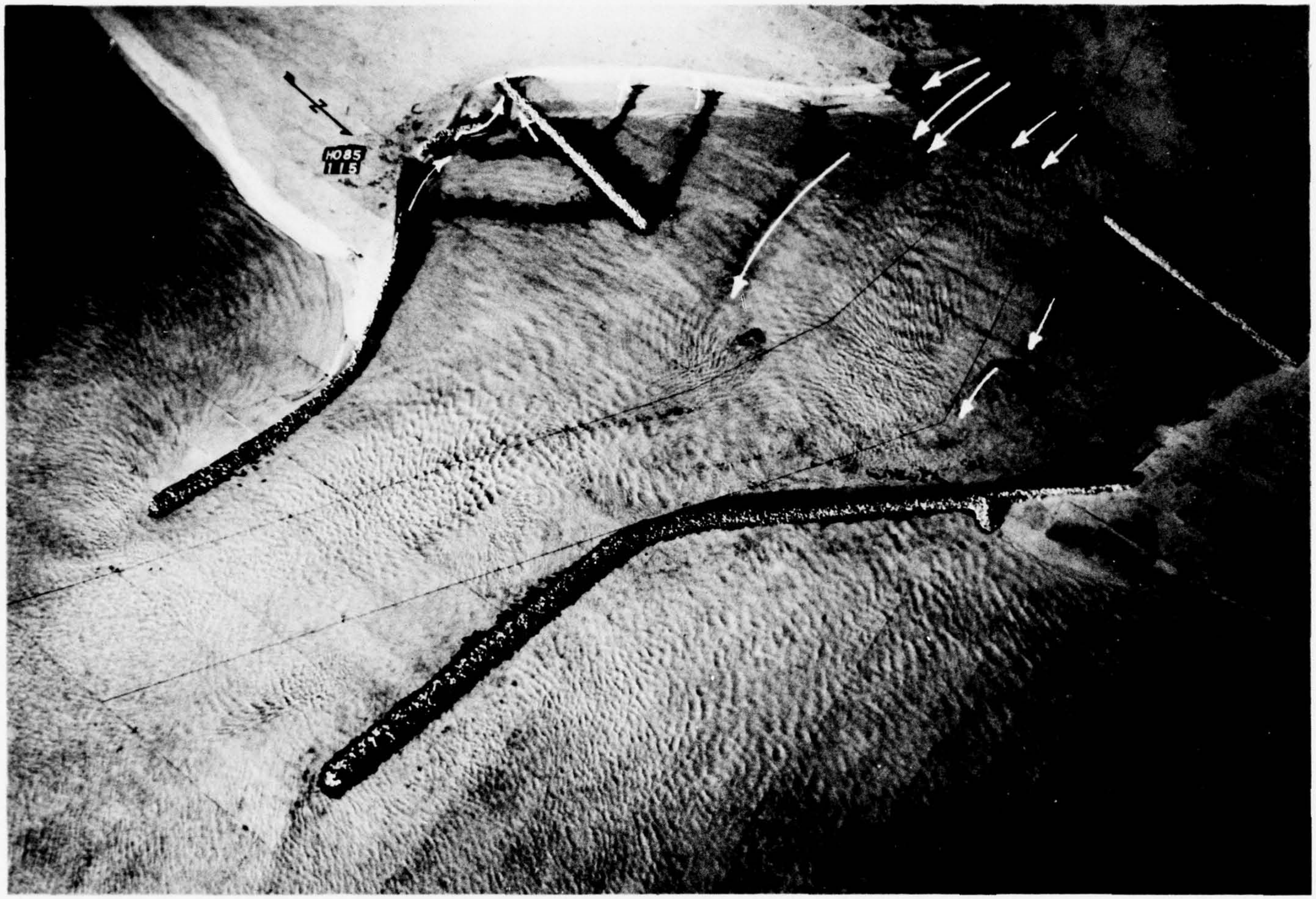


Photo 69. Typical tracer movement for plan 4 resulting from 7-sec, 8-ft waves from northeast for maximum ebb

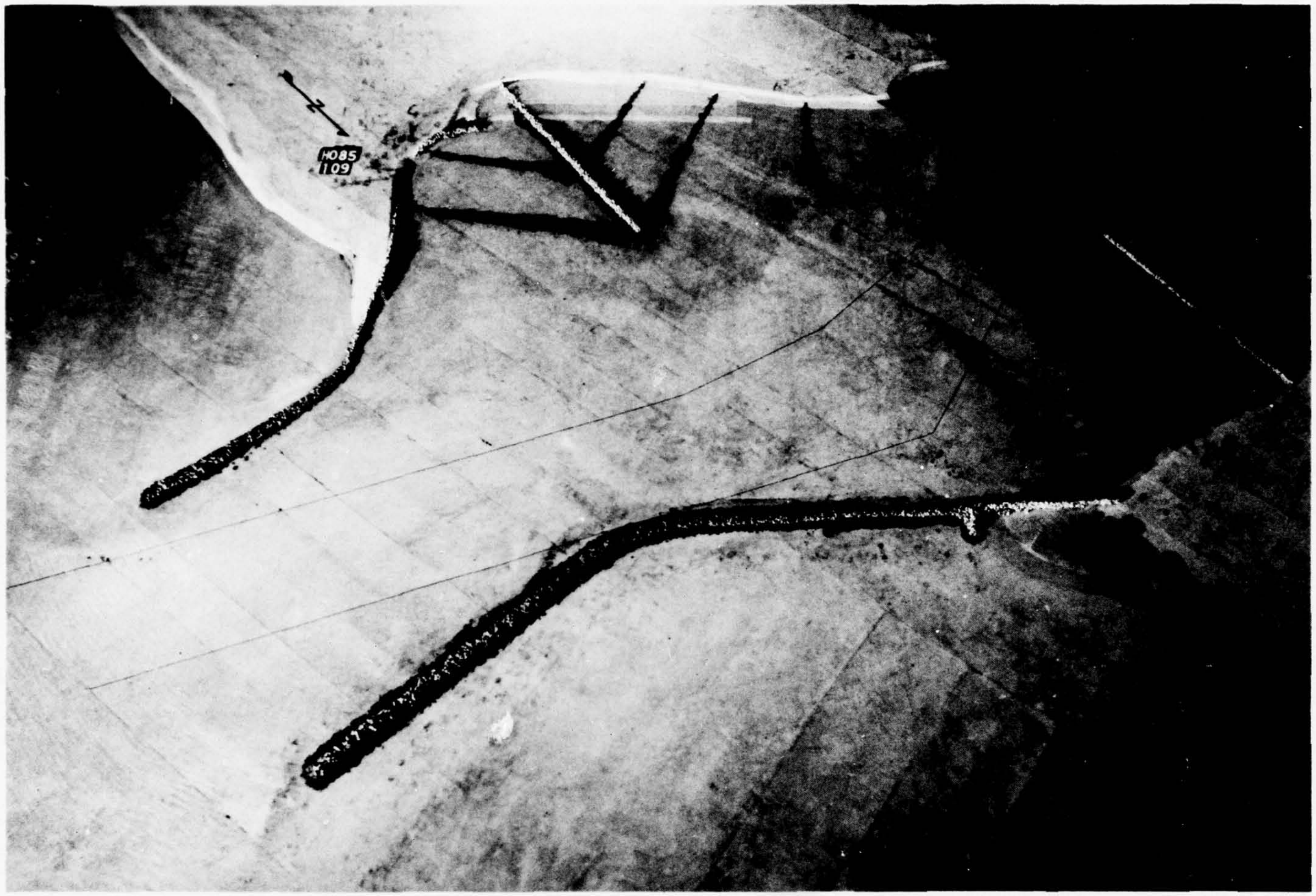


Photo 68. Tracer placement for plan 4

Photo 67. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 4; 11-sec, 9-ft waves from northeast for slack water

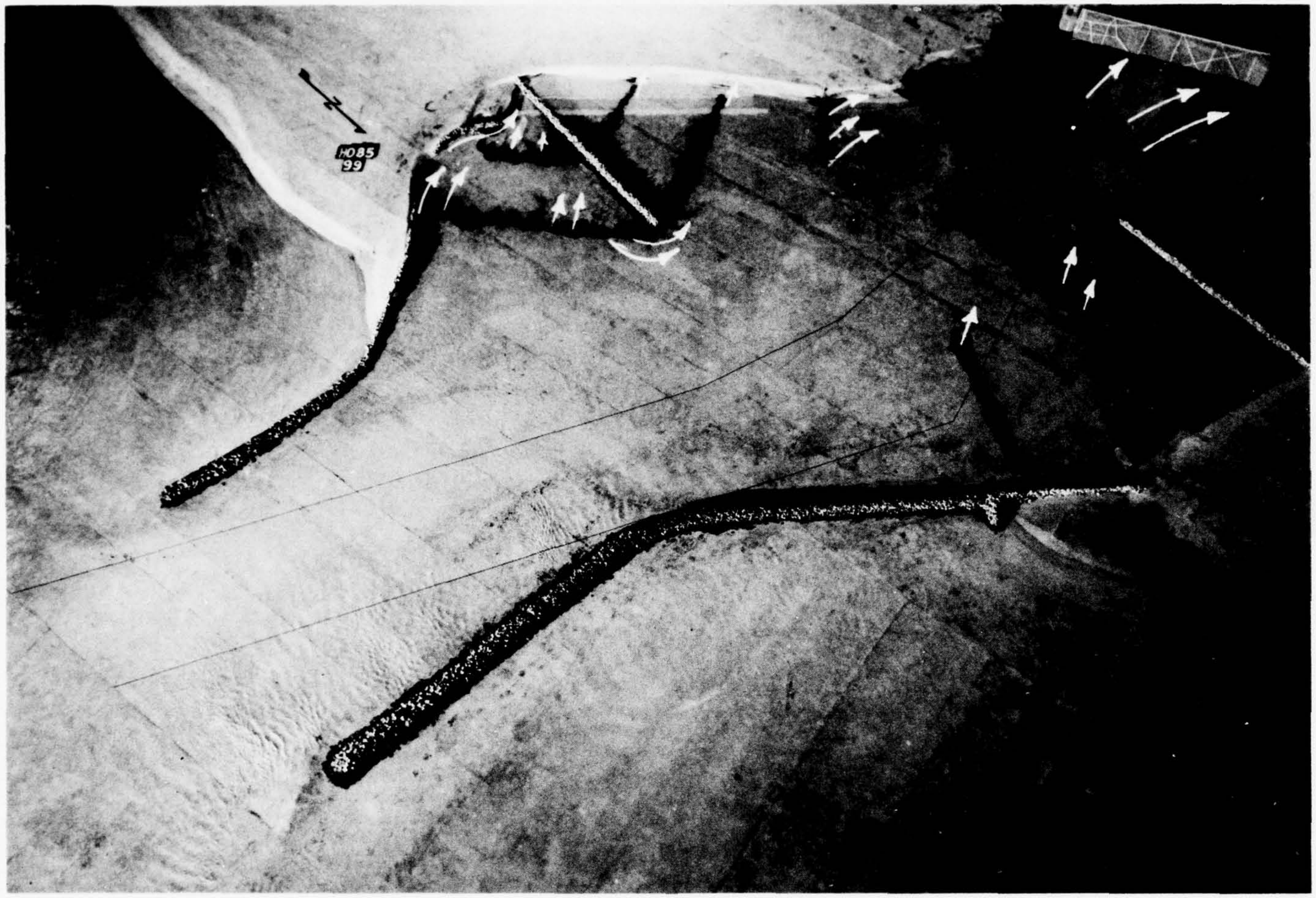


Photo 78. Typical tracer movement for plan 4A resulting from 7-sec, 8-ft waves from northeast for maximum flood

Photo 77. Typical tracer movement for plan 4A resulting from 7-sec, 8-ft waves from northeast for maximum ebb

Photo 76. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 4A; 11-sec, 9-ft waves from northeast for slack water

Photo 75. Typical wave and current patterns and current magnitudes (prototype feet per second) for plan 4A; 7-sec, 8-ft waves from northeast for slack water

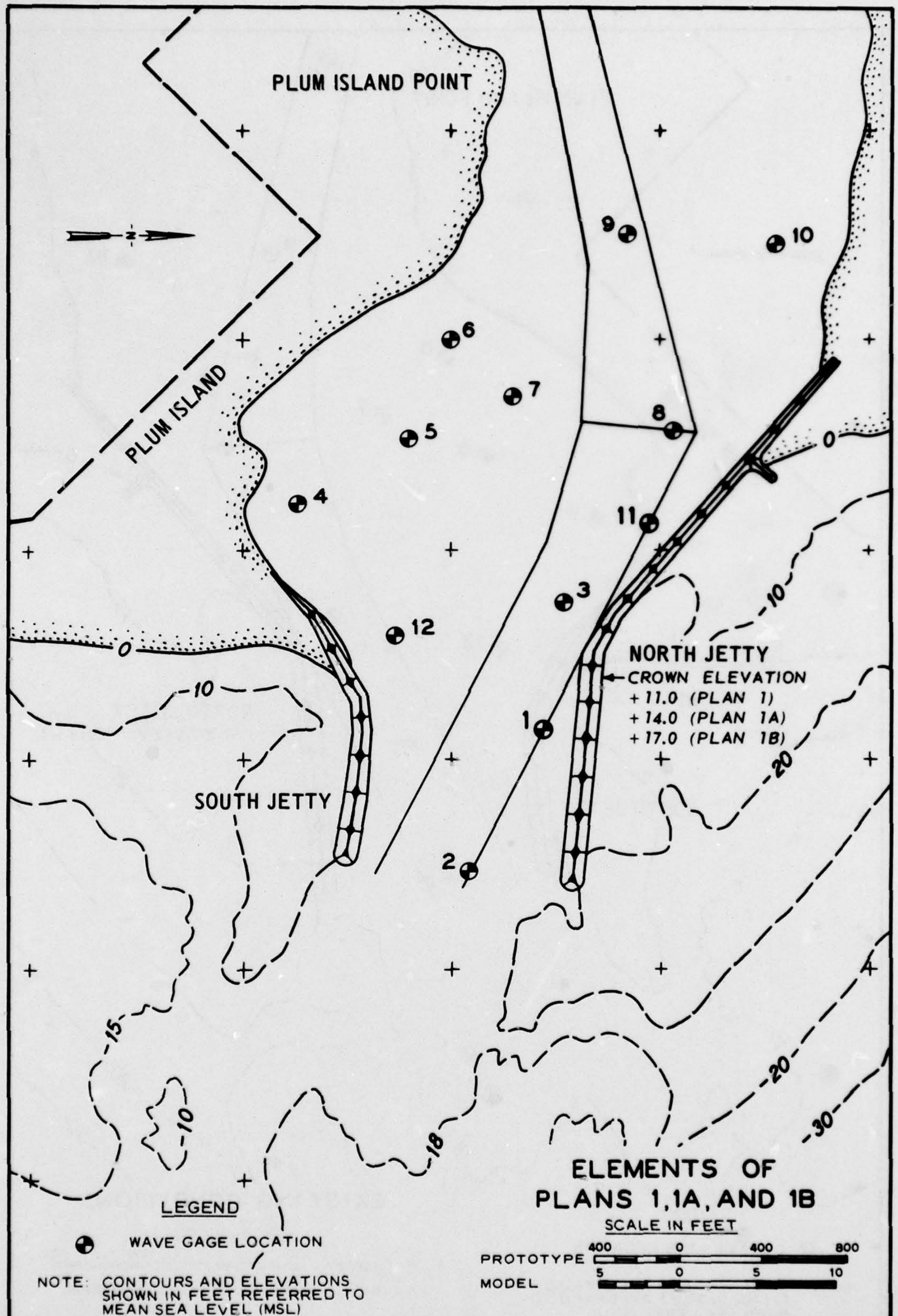

PLUM ISLAND POINT
PLUM ISLAND
N
9
10
6
7
8
5
4
11
3
12
0
10
NORTH JETTY
CROWN ELEVATION
+11.0 (PLAN 1)
+14.0 (PLAN 1A)
+17.0 (PLAN 1B)
1
20
SOUTH JETTY
2
15
10
18
20
30
ELEMENTS OF
PLANS 1,1A, AND 1B
LEGEND
WAVE GAGE LOCATION
NOTE: CONTOURS AND ELEVATIONS
SHOWN IN FEET REFERRED TO
MEAN SEA LEVEL (MSL)
SCALE IN FEET
PROTOTYPE 400 0 400 800
MODEL 5 0 5 10

PLATE 2

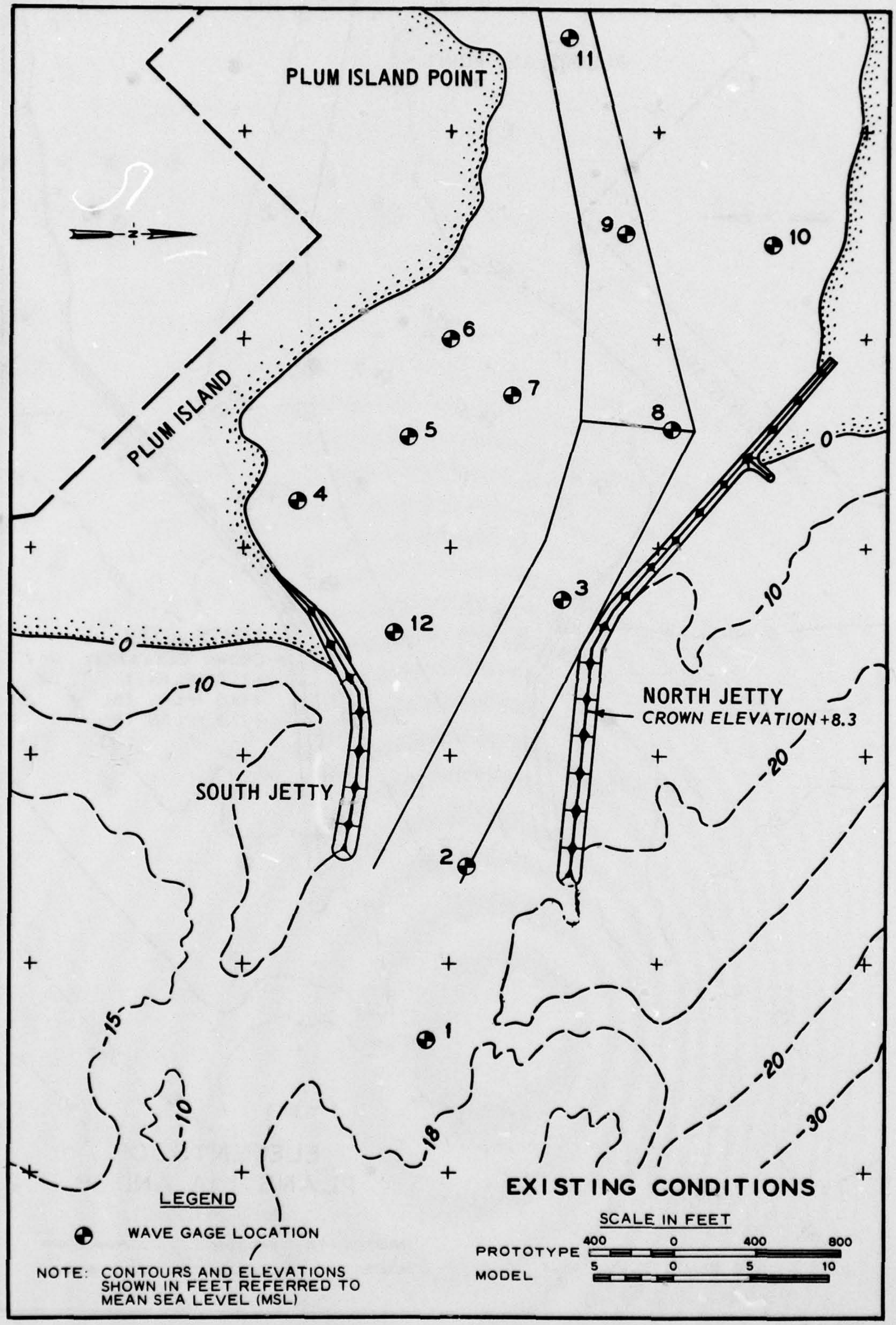

PLUM ISLAND POINT
PLUM ISLAND
SOUTH JETTY
NORTH JETTY
CROWN ELEVATION +8.3
0
10
15
18
20
30
1
2
3
4
5
6
7
8
9
10
11
12
EXISTING CONDITIONS
LEGEND
WAVE GAGE LOCATION
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN SEA LEVEL (MSL)
SCALE IN FEET
PROTOTYPE 400 0 400 800
MODEL 5 0 5 10

PLATE 1

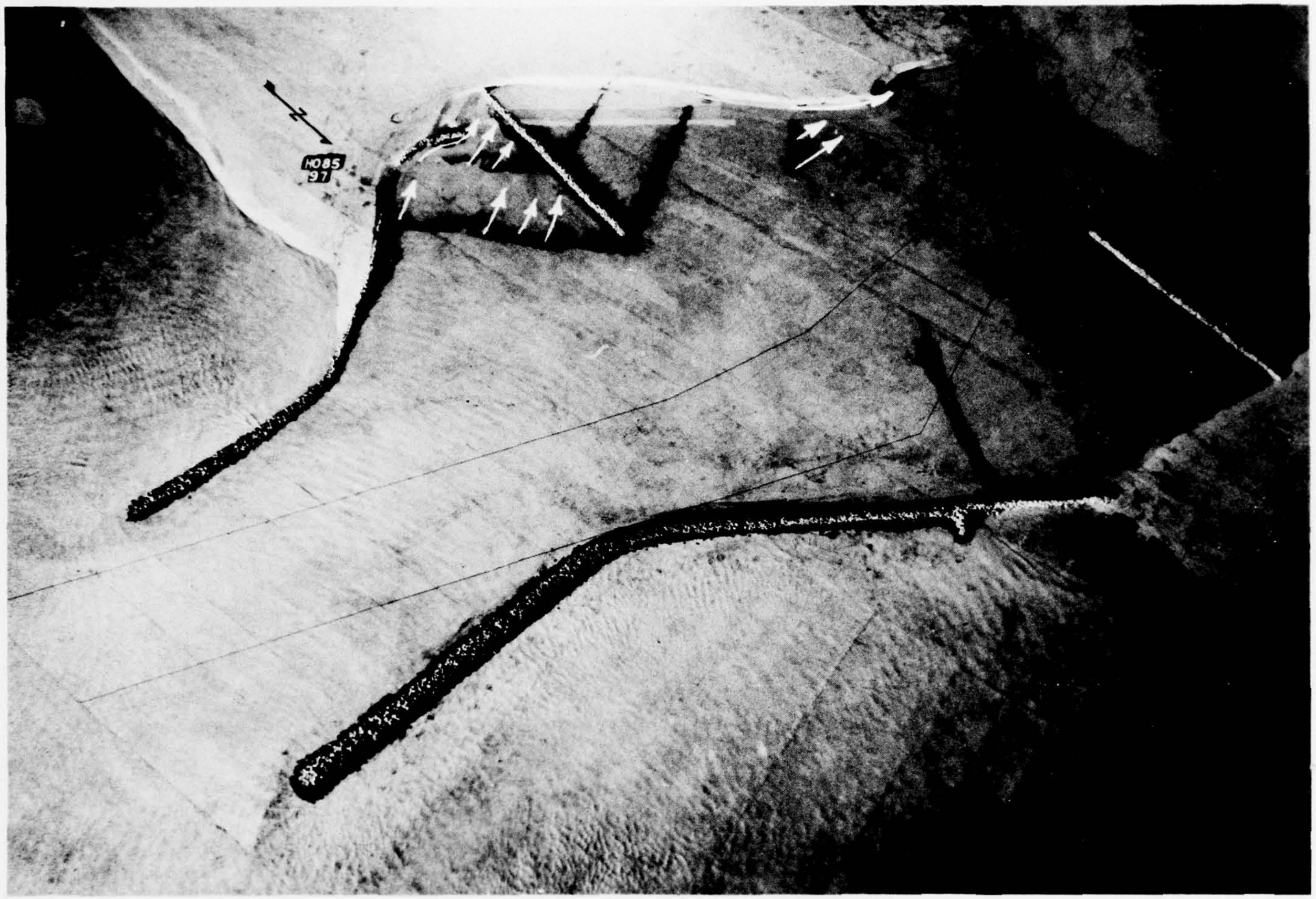


Photo 80. Typical tracer movement for plan 4A resulting from 11-sec, 9-ft waves from northeast for slack water

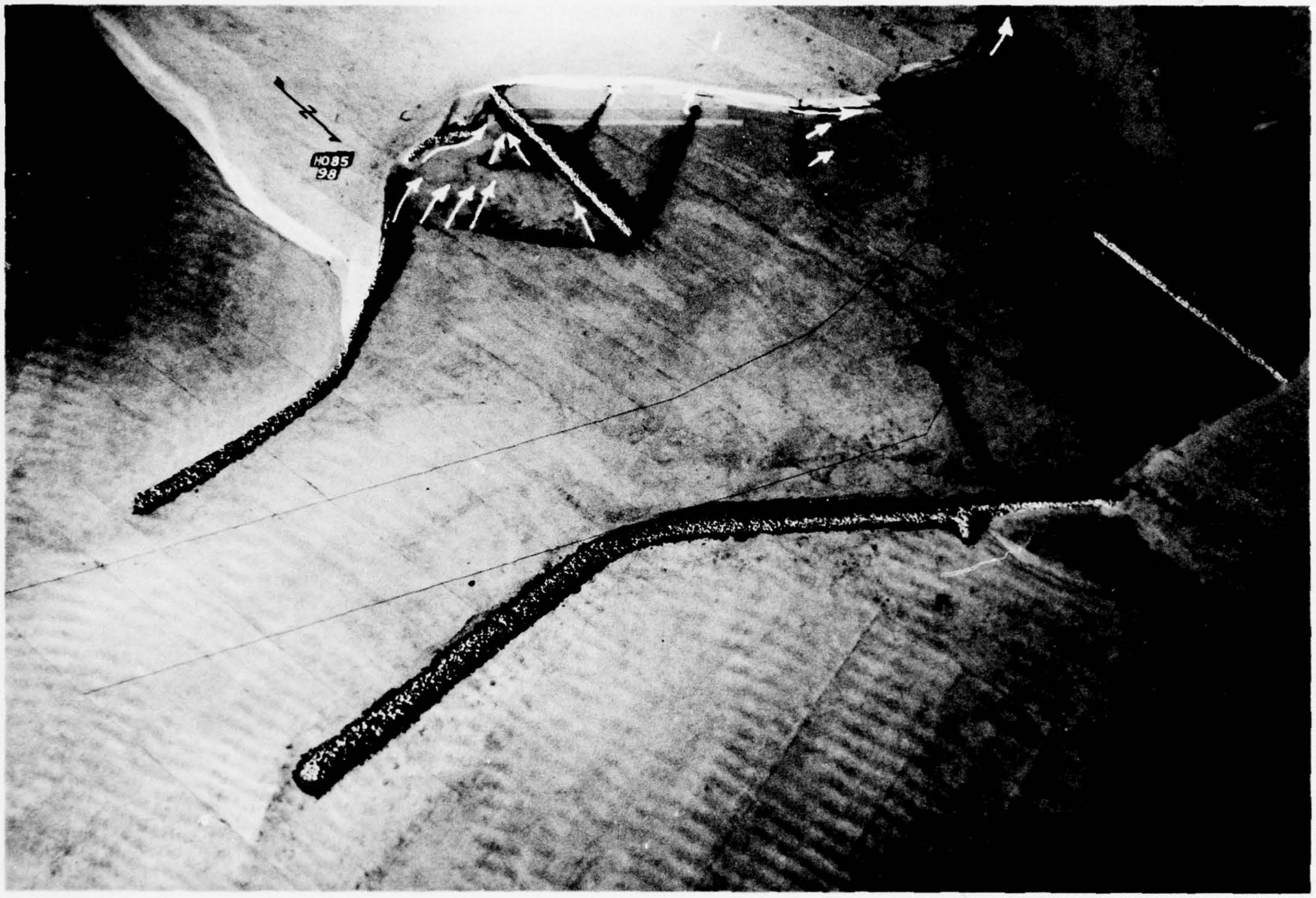


Photo 79. Typical tracer movement for plan 4A resulting from 7-sec, 8-ft waves from northeast for slack water

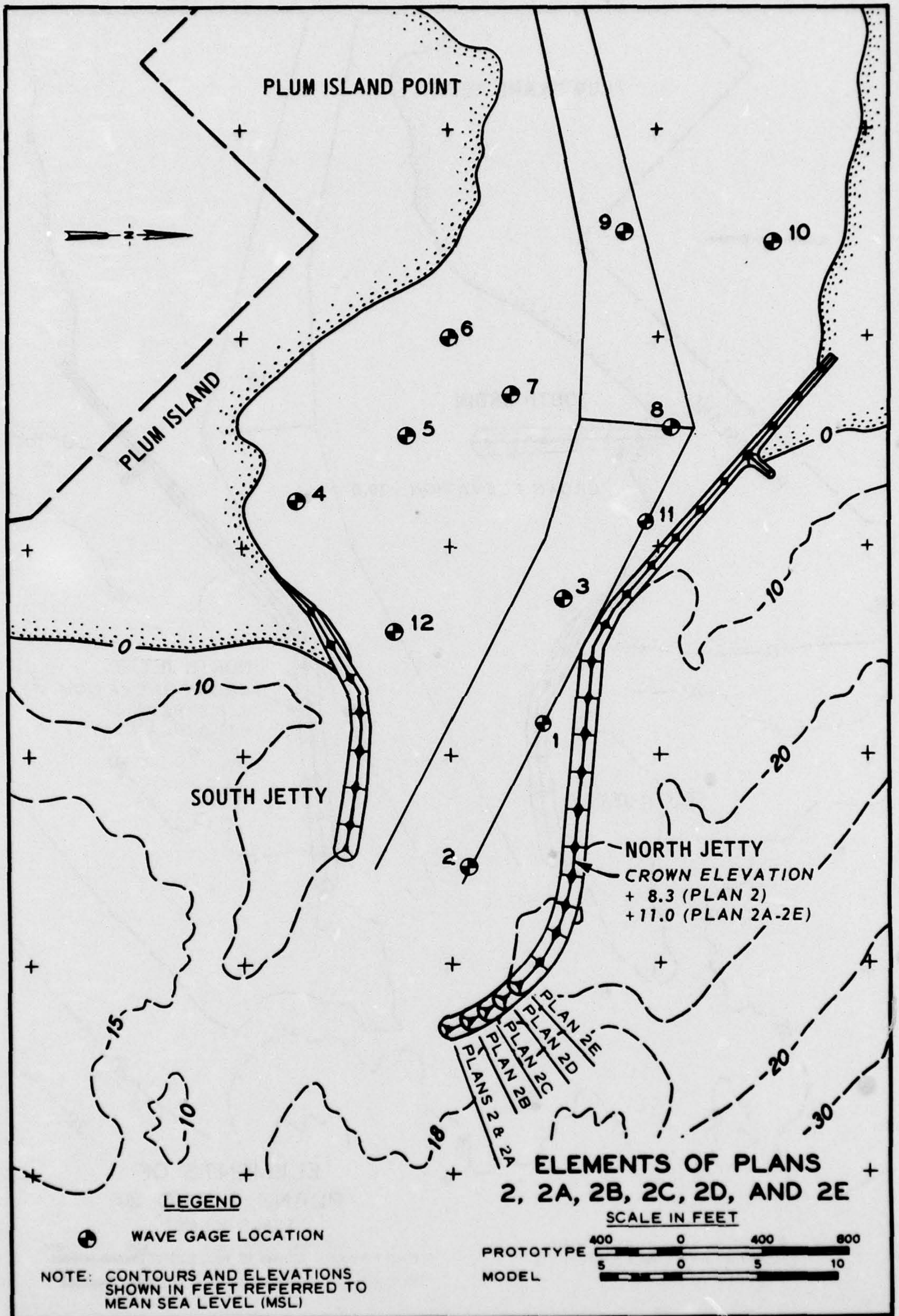

PLUM ISLAND POINT
PLUM ISLAND
N
9
10
6
7
8
5
4
0
11
3
12
10
1
20
SOUTH JETTY
NORTH JETTY
CROWN ELEVATION
+ 8.3 (PLAN 2)
+11.0 (PLAN 2A-2E)
2
PLAN 2E
PLAN 2D
PLAN 2C
PLAN 2B
PLANS 2 & 2A
15
10
18
20
30
ELEMENTS OF PLANS
2, 2A, 2B, 2C, 2D, AND 2E
SCALE IN FEET
PROTOTYPE 400 0 400 800
MODEL 5 0 5 10
LEGEND
WAVE GAGE LOCATION
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN SEA LEVEL (MSL)

PLATE 3

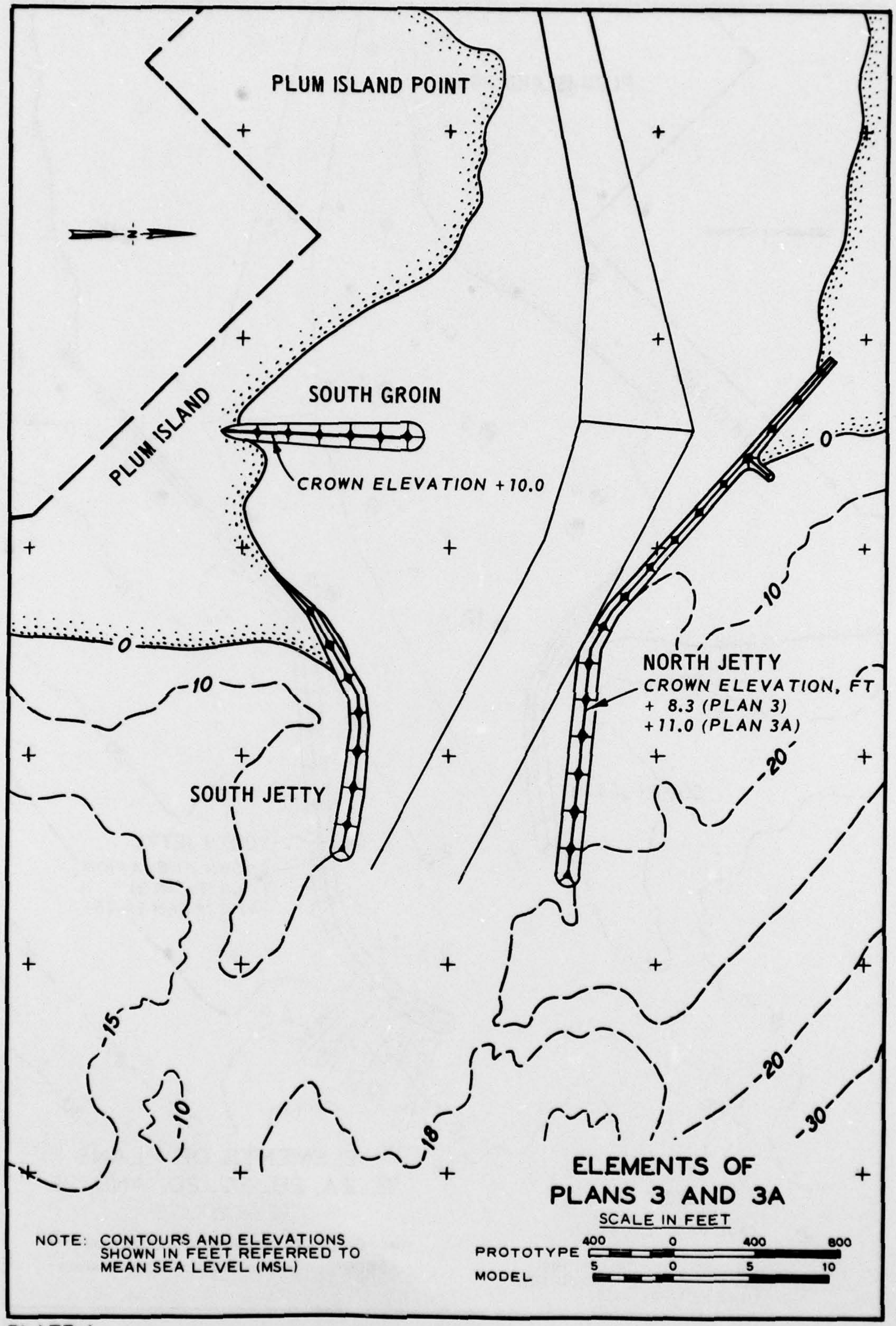
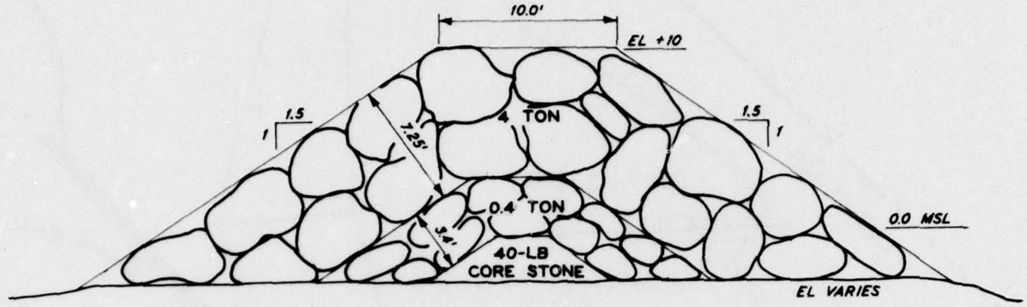
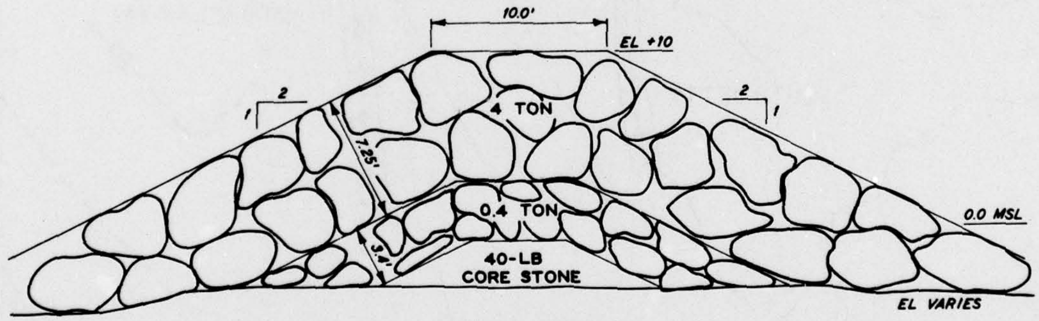

PLUM ISLAND POINT
PLUM ISLAND
SOUTH GROIN
CROWN ELEVATION +10.0
0
10
NORTH JETTY
CROWN ELEVATION, FT
+ 8.3 (PLAN 3)
+11.0 (PLAN 3A)
SOUTH JETTY
20
15
10
18
20
30
ELEMENTS OF
PLANS 3 AND 3A
SCALE IN FEET
PROTOTYPE 400 0 400 800
MODEL 5 0 5 10
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN SEA LEVEL (MSL)

PLATE 4

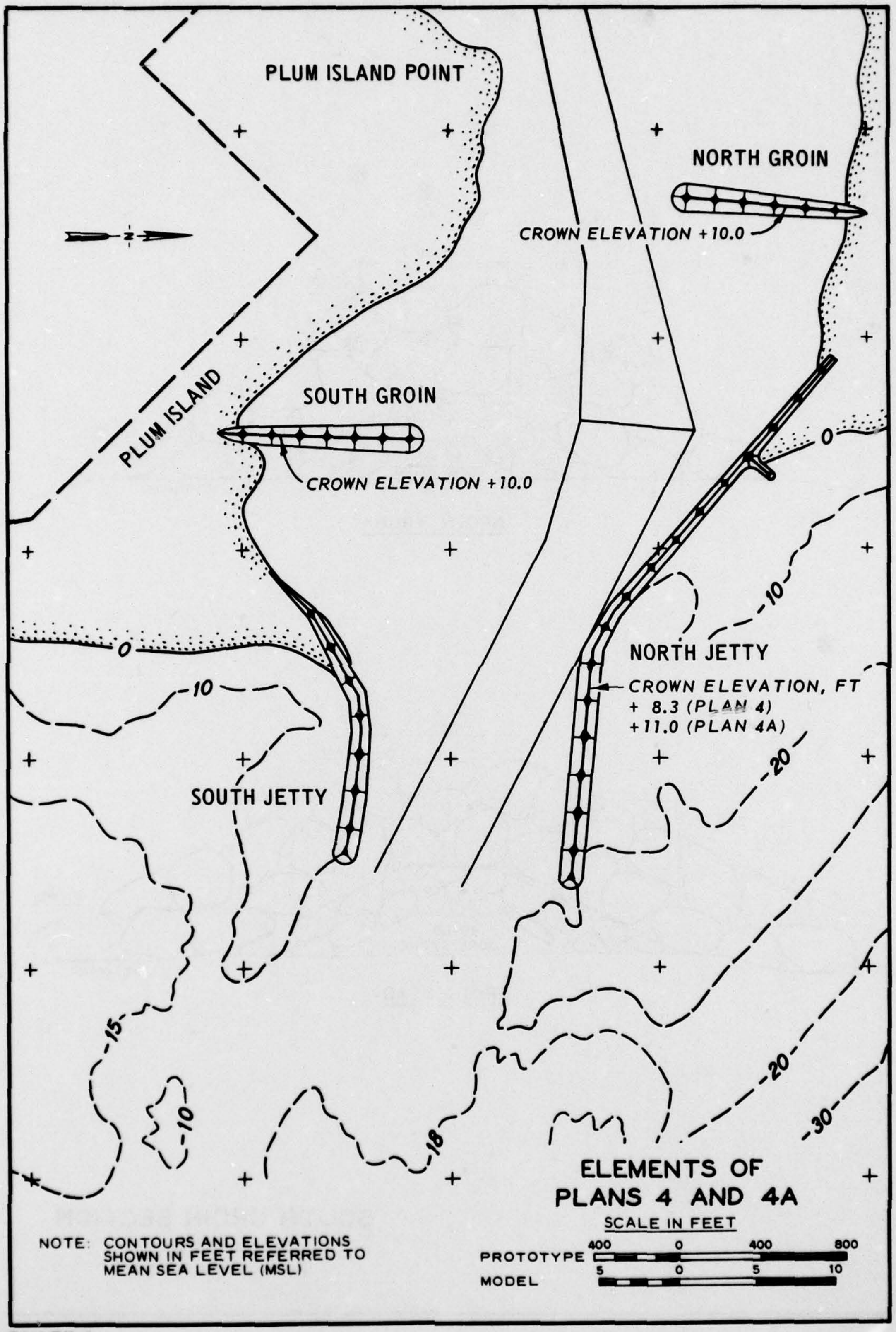


GROIN TRUNK

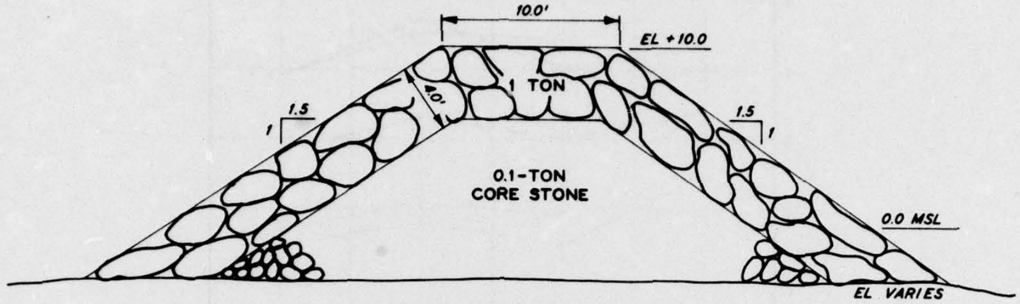


GROIN HEAD

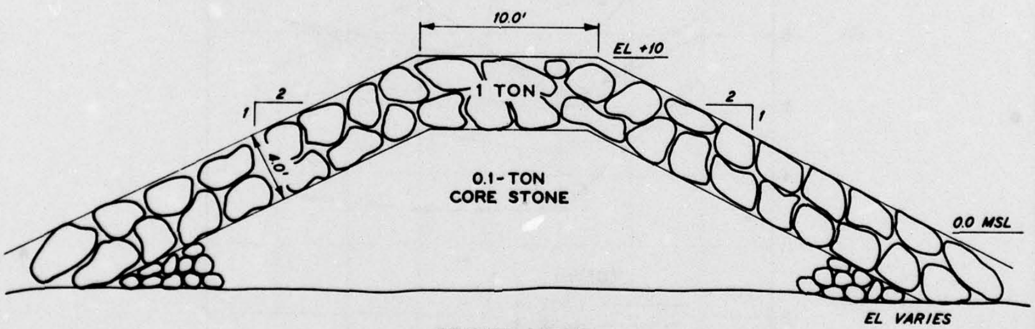
SOUTH GROIN SECTION
PLUM ISLAND
PLANS 3 AND 3A



PLUM ISLAND POINT
NORTH GROIN
CROWN ELEVATION +10.0
PLUM ISLAND
SOUTH GROIN
CROWN ELEVATION +10.0
0
10
NORTH JETTY
CROWN ELEVATION, FT
+ 8.3 (PLAN 4)
+11.0 (PLAN 4A)
SOUTH JETTY
20
15
10
18
20
30
ELEMENTS OF
PLANS 4 AND 4A
SCALE IN FEET
PROTOTYPE 400 0 400 800
MODEL 5 0 5 10
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN SEA LEVEL (MSL)



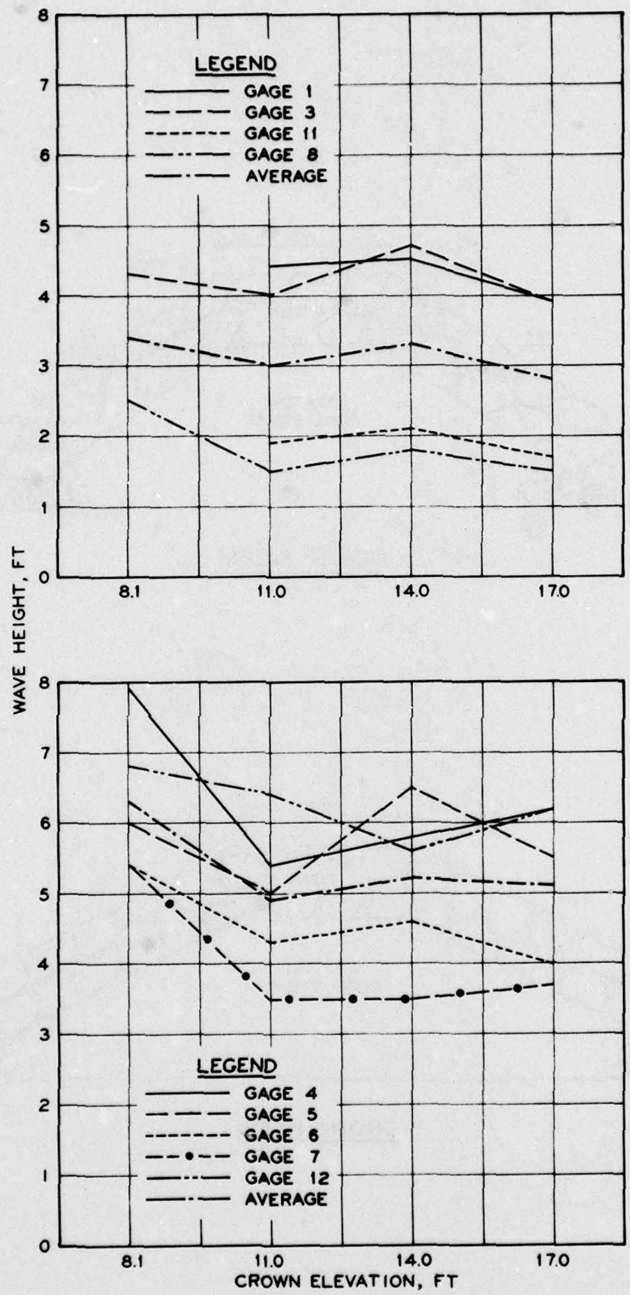
GROIN TRUNK



GROIN HEAD

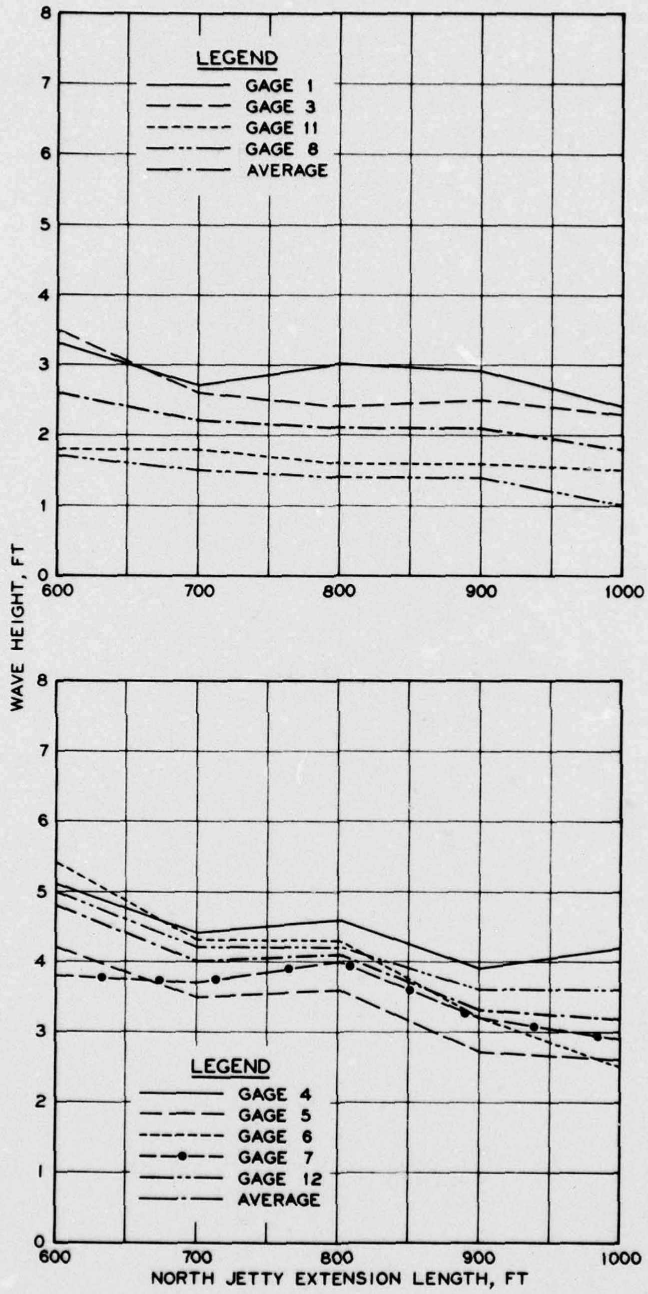
NORTH GROIN SECTION
SALISBURY BEACH
PLANS 4 AND 4A

PLATE 7



NORTH JETTY
CROWN ELEVATION
VS
WAVE HEIGHT

PLATE 8



NORTH JETTY
EXTENSION LENGTH
VS
WAVE HEIGHT

APPENDIX A: NOTATION

A	Area
b	Shallow-water orthogonal spacing
b_o	Deepwater orthogonal spacing
$(b_o/b)^{1/2}$	Refraction coefficient, K_r
D_{50}	Median particle diameter
H	Shallow-water wave height
H_o	Deepwater wave height
K_r	Refraction coefficient
K_s	Shoaling coefficient
L	Length
D	Discharge
T	Time
V	Velocity
$\forall$	Volume
γ	Specific weight
η_D	Ratio of median particle diameters
$\eta_{\gamma'}$	Ratio of apparent specific weight
λ	Horizontal scale
μ	Vertical scale

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Curren, Charles R

Newburyport Harbor, Massachusetts; Report 1: Design for wave protection and erosion control / by Charles R. Curren, Claude E. Chatham, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

28, ⌈92⌋ p., 9 leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; HL-79-1, Report 1)

Prepared for U. S. Army Engineer Division, New England, Waltham, Massachusetts.

References: p. 28.

1. Bank erosion. 2. Bank protection. 3. Erosion control. 4. Hydraulic models. 5. Newburyport Harbor, Mass. I. Chatham, Claude E., joint author. II. United States. Army. Corps of Engineers. New England Division. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; HL-79-1, Report 1.

TA7.W34 no.HL-79-1 Report 1